U.S. Department of the Interior
U.S. Geological Survey

Evaluation of the Effectiveness of an Urban Stormwater Treatment Unit in Madison, Wisconsin, 1996–97

Water-Resources Investigations Report 99–4195





Prepared in cooperation with the
City of Madison, and the
Wisconsin Department of Natural Resources

USGS
science for a changing world

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By R.J. Waschbusch

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WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Middleton, Wisconsin
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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	0.4048	hectare
square mile (mi^2)	2.590	square kilometer
pound (lb)	453.6	gram
ton (short)	0.9072	megagram (mg)

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Another unit of measurement used in this report is micrometers (μm).

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Abstract

An urban stormwater treatment unit was tested as part of an ongoing program of urban nonpoint-pollution research in Madison, Wis. Flow measurements were made and water samples were collected at the inlet to, outlet from, and bypass around the treatment chamber of the device that was installed to collect the runoff from a city maintenance yard.

About 90 percent of the runoff water from the 4.3-acre basin was treated by the unit. The remaining 10 percent bypassed the treatment chamber when the flow rate reached approximately 500 gallons per minute.

A 24-percent difference between the estimated amount (405 kilograms) and the actual amount (536 kilograms) of retained material in the treatment chamber may be attributed to bedload material that the automatic samplers could not effectively collect. Assuming this, 8 percent of the total mass in the untreated runoff water was estimated as the unsampled bedload.

On the basis of water-sample data collected over the course of the study, the suspended solids removal efficiency of treatment chamber was about 25 percent, and the efficiency of the unit as a whole was 21 percent. If the unsampled bedload material was accounted for, the treatment-chamber efficiency was 33 percent.

About 19 percent of the total phosphorus was removed from the water that passed through the treatment chamber and 17 percent was removed by the unit as a whole. Total polycyclic aromatic hydrocarbon (PAH) loads were reduced about 39 percent by the treatment chamber and 34 percent by the unit as a whole; these were some of the most effectively removed constituents. Total metals were reduced about 20 to 30 percent by both the treatment chamber and the unit as a whole. In general, dissolved constituents were unaffected by the unit.

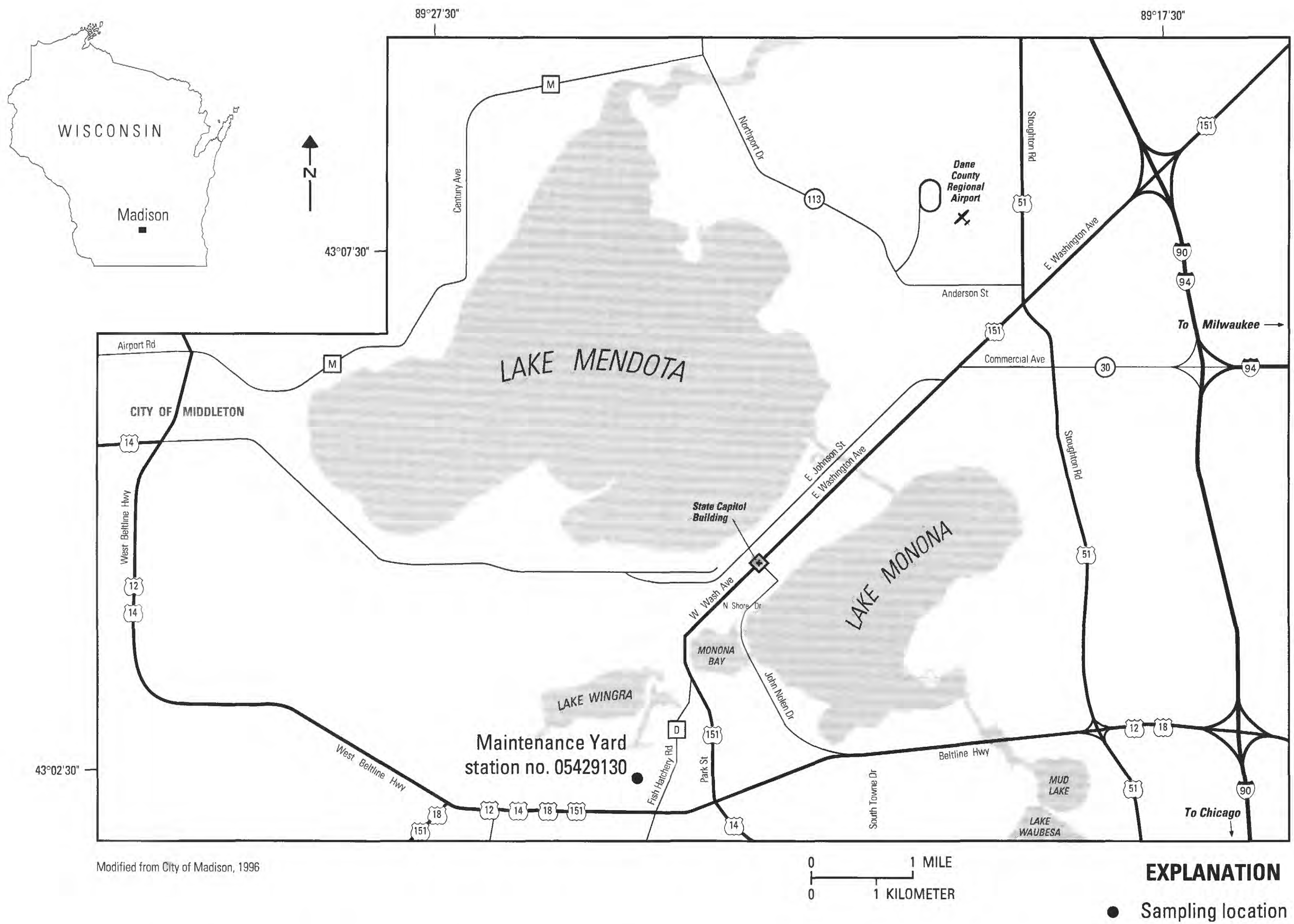
The material retained in the treatment chamber had high concentrations of lead and PAH and may be subject to special disposal restrictions based on those concentrations and the presence of benzo(*a*)anthracene. The chemical makeup of the retained material in other similar stormwater treatment units will probably vary depending on the land use and activities in the drainage basin.

INTRODUCTION

Since the passage of the Clean Water Act in 1987, municipalities with populations greater than 100,000 have been required to monitor and control the quality of their stormwater discharge. Installing stormwater treatment devices developed for this purpose is one way for urban areas to comply. The U.S. Geological Survey (USGS), in cooperation with the City of Madison, Wis., and the Wisconsin Department of Natural Resources (WDNR), characterized runoff from a maintenance yard and evaluated the effectiveness of a stormwater treatment unit as part of an ongoing study of the quantity and quality of urban runoff and to evaluate potential monitoring and remediation systems and other best management practices (Waschbusch, 1995; Steuer and others, 1997; Bannerman and others, 1993; Corsi and others, 1995; Stuntebeck and Bannerman, 1998).

In May 1996, a Stormceptor model STC 6000 was installed in a storm sewer system in Madison, Wis., that collects runoff from a 4.3-acre city maintenance yard (fig. 1). According to sizing guidelines in product literature, this unit should treat from 82 to 93 percent of the annual flow coming off this area, resulting in approximately 80 percent suspended solids removal (Stormceptor Corporation, 1997).

Buried underground, the unit does not require any above-ground space, so it may be practical for intensively developed urban areas. The unit is manufactured in several sizes; the one installed for this study has a treatment-chamber diameter of 10 ft and a total holding



Modified from City of Madison, 1996

Figure 1. City of Madison, Wis., and location of maintenance yard where stormwater treatment unit was installed.

capacity of 6,130 gal. Water flowing through the storm sewer is directed into the treatment chamber, where solids settle and material less dense than water, like oil and grease, rise and are trapped (fig. 2). In other studies, effectiveness of the unit for reducing contaminant levels was estimated by using pollutant-runoff models and measurements of sediment trapped in field installations (Weatherbe and others, 1995; Bryant and others, 1995). In this study, paired sampling was used to measure the efficiency of the unit at reducing stormwater pollutants.

From August 1996 until May 1997, flow measurements were made and water samples were collected during 45 runoff events at the inlet to, outlet from, and bypass around the treatment chamber of the unit (USGS station nos. 05429130, 05429131, and 05429132, respectively). On the basis of these monitoring data, efficiency of the unit at removing various pollutants was calculated. At the end of the monitoring period, the amount of material retained in the treatment chamber (USGS station no. 05429133) was also measured and analyzed for comparison to water sampling results and to determine if disposal restrictions would apply.

The purpose of this report is to make available these monitoring results so as to provide specific information regarding the effectiveness of this or similar stormwater treatment units for use in treating runoff from impervious areas of several acres in this type of urban setting.

Study-Area Description

The 4.3-acre public works maintenance yard where the stormwater treatment unit was installed is used for yard-waste dropoff; fueling, storage, and cleaning of city utility and maintenance vehicles; and storage of sand and salt for road application (fig. 3). Asphalt and rooftop cover most of the surface area of the site. Characteristics of the site are listed in table 1. Stormwater from the study area flows from the asphalt, through three inlet grates into the storm sewer system, and into the unit. Water that enters the unit flows through a treatment chamber before it continues through the storm sewer system and eventually empties into Lake Wingra. During periods of high flow, some of the flow that enters the unit bypasses the treatment chamber and continues through the storm sewer system without treatment (fig. 2).

Acknowledgments

A number of people made this study successful and there are several we would like to acknowledge. Thanks to Steven Greb and Roger Bannerman (WDNR) for their insights during the data interpretation, John Pfender (WDNR) for his work initiating the study and for his timely review of the report manuscript, and Mary Ellen Testen and the rest of the City of Madison Department of Public Health Laboratory personnel who were always available for sample analyses and additional quality control work. Greg Fries and Jeff Benedict from the City of Madison Engineering Division were extremely helpful selecting the site and making arrangements for the installation of the unit and equipment. David Owens' (USGS) instrumentation expertise was greatly appreciated. Thanks to David Eberle (USGS) for the long and unusual hours collecting and processing samples and much of the day-to-day operations to keep the monitoring running successfully and to Susan Jones for her help with the manuscript. Lastly, we would like to thank the Stormceptor Corporation and Graham Bryant in particular, for his helpfulness with questions regarding the unit and his insights during the data interpretation.

STUDY APPROACH AND METHODS

From August 1996 through April 1997, a total of 45 flow-composite water samples were collected during runoff periods (referred to hereafter as "events") at the inlet and the outlet. Flow-composite sampling means that a subsample was collected every time a specifed volume of water passed the sample point. The composite sample thus represents the average constituent concentration during the runoff event. During periods of high flow, time-composite samples were collected from water bypassing the treatment chamber. Time-composite sampling means that a subsample was collected at a fixed time interval, in this case every 5-minutes. Samples collected in this manner do not represent the average constituent concentration during the runoff event. Of the 45 samples, 15 were analyzed for constituents listed in table 2; the remaining 30 samples were analyzed for total and suspended solids and total and dissolved phosphorus only. Many of the 30 samples that were analyzed only for solids and phosphorus were from snowmelt that did not produce substantial runoff. If the following three criteria were met, the sample was analyzed for the complete constituent list detailed in

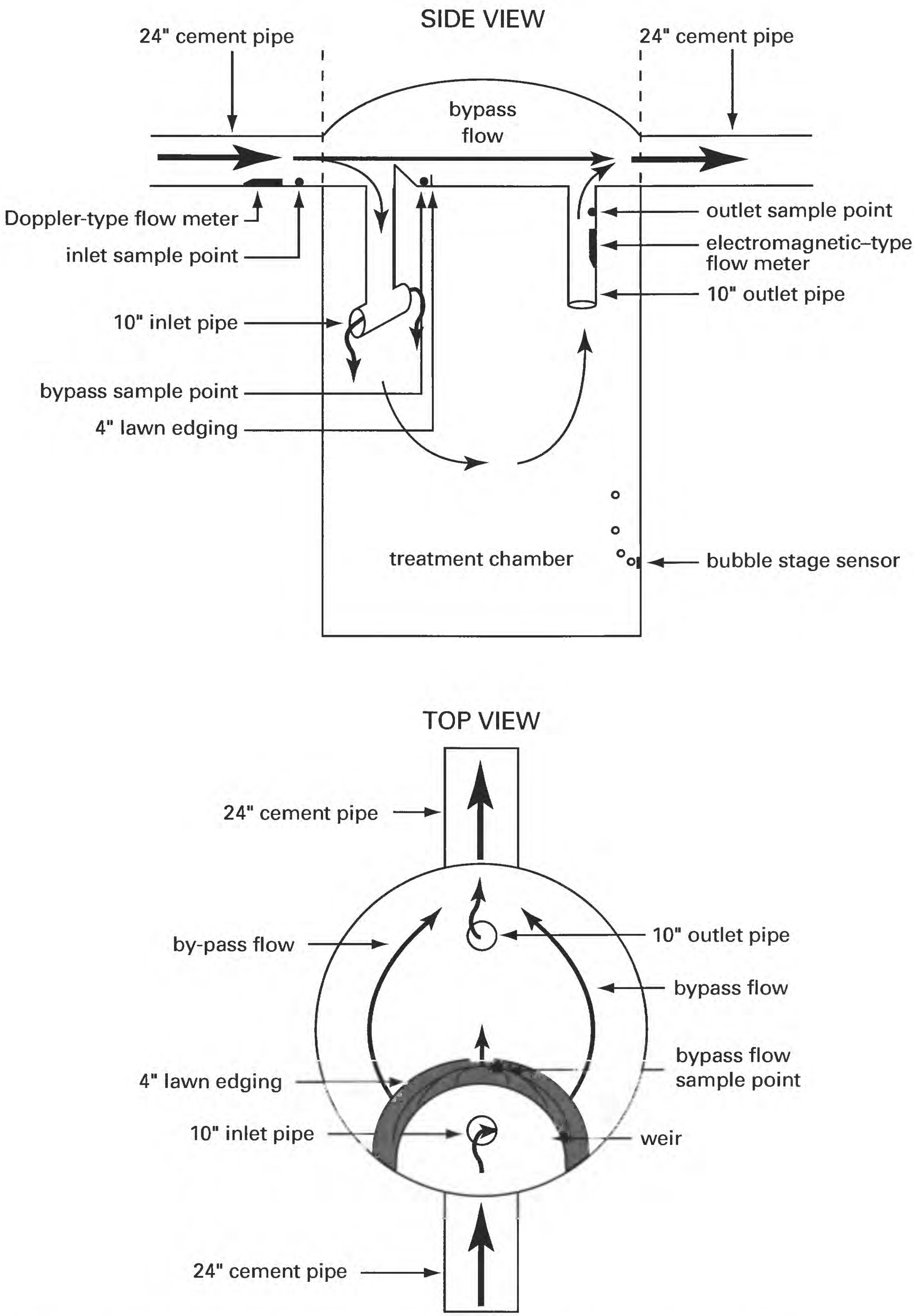


Figure 2. Diagram of stormwater treatment unit and instrumentation for the Madison, Wis., study.

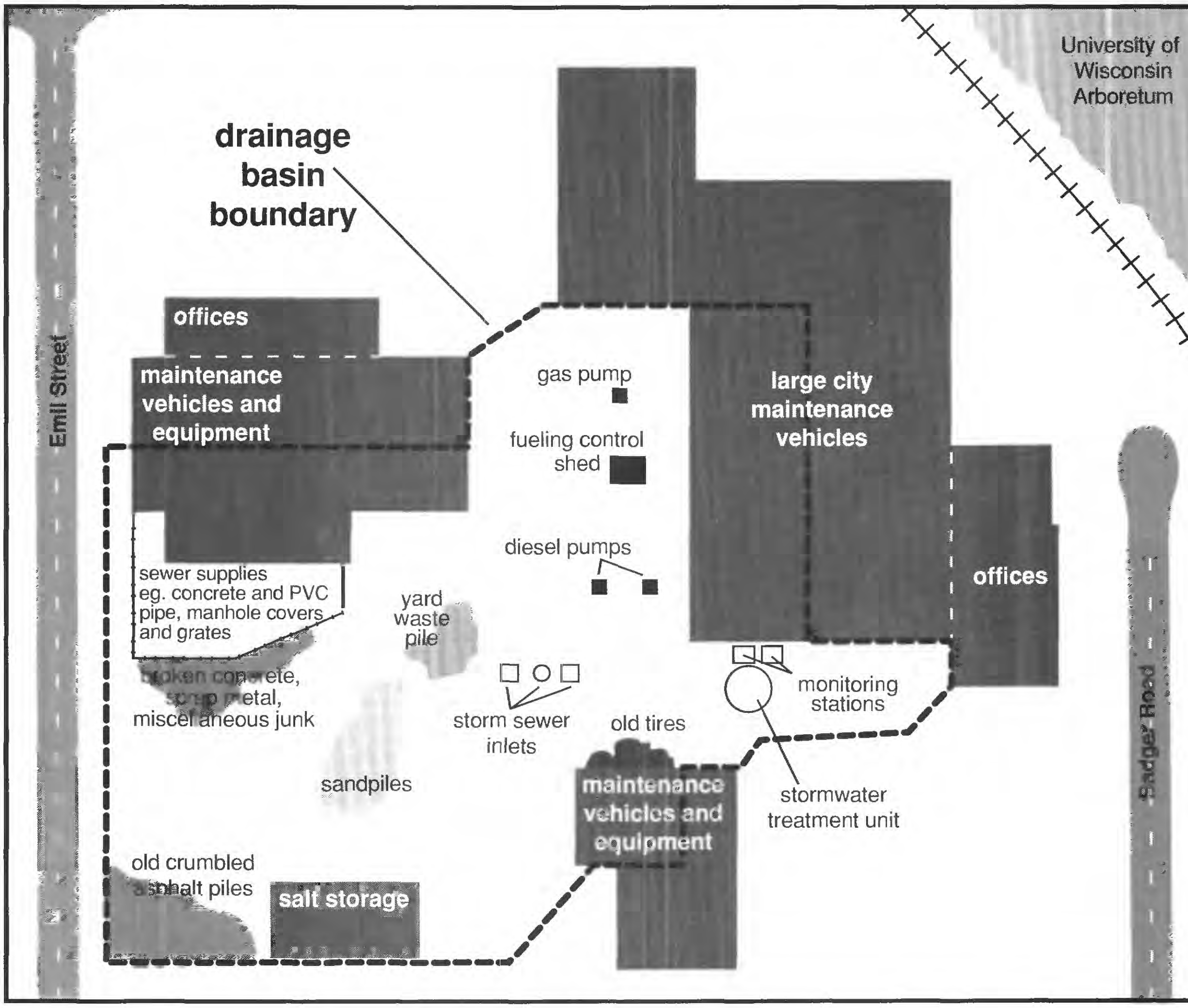


Figure 3. Diagram of public works maintenance yard where stormwater treatment unit was tested in Madison, Wis., 1996–97.

table 2; otherwise, only solids and phosphorus analyses were done:

- Sufficient sample volume for laboratory analysis
- Equipment working at both the inlet and outlet
- A sufficient number of samples were collected at intervals that could accurately represent the runoff period.

In addition to the 45 sampled events, 15 events were identified but not sampled because of equipment malfunctions. In most of these cases, flow was measured and in a few cases, flow was estimated on the basis of incomplete data. In all cases, concentrations of solids and phosphorus were estimated using concentrations from events that were similar in runoff volume and time of year. These concentration estimates were used solely in a solids mass balance exercise.

The runoff volumes and solids concentrations (including the 15 sets of estimated values) were used to calculate solids loads into and out of the treatment chamber. By summing these loads over the entire monitoring period, a mass of solids retained in the treatment chamber was calculated. After the monitoring period ended, measurements were made to determine the actual amount of solids retained by the treatment chamber and then compared to the calculated value based on the water sampling.

The equipment was installed and tested two months before monitoring began. After the testing period, the sediment in the treatment chamber was removed and the chamber was thoroughly cleaned.

Table 1. Characteristics of stormwater treatment monitoring site (USGS site no. 05429130)

Characteristic	Value
Latitude	43°02'16"
Longitude	89°24'15''
Drainage area	4.3 acres
Percent impervious	100
Land-use	public works maintenance yard
Surrounding land use	light industrial, commercial and arboretum
Pavement type	asphalt
Type of vehicles using the yard	street maintenance and garbage trucks and passenger vehicles carrying yard waste
Approximate number of vehicles stored at the site	100
Number of diesel fueling pumps	2
Number of unleaded gas fueling pumps	1

Collection of Flow, Precipitation, and Water-Quality Data

A continuous-record gaging station was used to monitor stormwater flow, precipitation, and water quality. Velocity and water level in the 24-in. storm sewer pipe that leads into the stormwater unit was measured with a Doppler-type velocity-area meter (fig. 2). A second meter, an electromagnetic velocity meter, was installed in the 10-in. pipe that exits the treatment chamber. Velocity and water level were used to compute the flow volume. A bubble line connected to a pressure transducer in the gage house measured the water level in the treatment chamber. Flow-composite water samples were collected by means of refrigerated automatic point samplers. These samples represent the average constituent concentrations during a runoff period on a discharge-weighted basis. Influent samples were collected from the 24-in. pipe approximately 6 ft upstream from where the water entered the unit. Treated samples were collected from the 10-in. pipe that exits the treatment chamber. Water samples that bypassed the treatment chamber were collected in time-composite fashion from the bypass chamber by means of a nonrefrigerated automatic point sampler. A strip of 4-in. plastic landscape edging was anchored to the bypass chamber just beyond the weir to prevent treated outlet water from mixing with bypass water. Treated-water samples that met previously listed criteria were analyzed for the constituents listed in table 2; otherwise, the samples were analyzed for solids and phosphorus. All bypass samples were analyzed only for solids and phosphorus.

Continuous precipitation data were collected with a tipping bucket rain gage. This gage was not designed to measure snowfall, however, so precipitation values from November 21, 1996, to March 28, 1997, and April 11 to 18, 1997, may not be accurate. A Campbell Scientific CR10 datalogger recorded all discharge and rainfall data and initiated sample collection through the automatic samplers. Data were automatically downloaded every morning to a USGS office in Madison. Runoff samples were analyzed by the City of Madison Department of Public Health (MDPH), the Wisconsin State Laboratory of Hygiene (WSLH), and the University of Alabama at Birmingham (UAB) Stormwater Laboratory. Both the MDPH and WSLH laboratories are certified by the State of Wisconsin and the U.S. Environmental Protection Agency and participate in the USGS laboratory verification program.

Analysis of Material Retained in the Treatment Chamber

At the conclusion of the monitoring period, to determine the amount of sediment collected in the treatment chamber during the study period, plugs were placed in the inlet to and outlet from the treatment chamber to prevent any additional water and associated sediment from entering or exiting the treatment chamber. Three weeks later, the plugs were removed and the water was pumped out of the chamber using a submersible pump that was kept just below the water surface. At each 6-in. drop in water level, water samples were collected and the level was recorded. These samples were analyzed for solids and phosphorus.

When the water level in the treatment chamber decreased to 1.4 ft, pumping was halted and measure-

Table 2. Constituent list and laboratory performing sample analysis
[X, analysis performed; --, not applicable; MDPH, Madison Department of Public Health Laboratory[1]; WSLH, Wisconsin State Laboratory of Hygiene[1]; UAB, University of Alabama; Std. Meth., (American Public Health Association 1995); SW846, (USEPA 1986); EPA (Kopp and McKee 1979); Coulter counter, (British Standards Institution 1983); ASTM, (American Society for Testing and Materials 1998)]

Target Constituent	Total	Dissolved	Laboratory	Method
Solids	X	X	MDPH	Std. Meth 2540B, 2540D
Biological oxygen demand	X	X	MDPH	Std Meth. 5210B
Chemical oxygen demand	X	X	MDPH	Hach ULL or LL Method 8000
Phosphorus	X	X	MDPH	Std. Meth. 4500PE, EPA 200.7
Nitrate plus nitrite	--	X	MDPH	EPA 300.0A
Ammonia-nitrogen	X	--	MDPH	Std. Meth. 4500 NH_3 B&C
Chloride	--	X	MDPH	EPA 300.0A
Specific conductance	X	--	MDPH	Std. Meth 2510 B
pH	X	--	MDPH	Std. Meth 4000-H+B
Hardness	X	--	MDPH	EPA 200.7
Alkalinity	X	--	MDPH	Std. Meth 2320
Cadmium	X	X	MDPH	Std. Meth 3113 B
Copper	X	X	MDPH	Std. Meth 3111 B or C or Std. Meth 3113 B
Lead	X	X	MDPH	Std. Meth 3111 B or C or Std. Meth 3113 B
Zinc	X	X	MDPH	Std. Meth 3111 B or C
Organic carbon	X	X	WSLH	SW846, 9060
Particle size	--	--	UAB	Coulter counter
Microtoxicity	--	--	WSLH	ASTM D5660-96
Polycyclic aromatic hydrocarbons				
Acenaphthene	X	X	WSLH	SW846, 8310
Acenaphthylene	X	X	WSLH	SW846, 8310
Anthracene	X	X	WSLH	SW846, 8310
Benzo[*a*]anthracene	X	X	WSLH	SW846, 8310
Dibenzo[*a,h*]anthracene	X	X	WSLH	SW846, 8310
Chrysene	X	X	WSLH	SW846, 8310
Fluoranthene	X	X	WSLH	SW846, 8310
Benzo[*b*]fluoranthene	X	X	WSLH	SW846, 8310
Benzo[*k*]fluoranthene	X	X	WSLH	SW846, 8310
Fluorene	X	X	WSLH	SW846, 8310
Naphthalene	X	X	WSLH	SW846, 8310
Benzo[*g,h,i*]perylene	X	X	WSLH	SW846, 8310
Phenanthrene	X	X	WSLH	SW846, 8310
Pyrene	X	X	WSLH	SW846, 8310
Benzo[*a*]pyrene	X	X	WSLH	SW846, 8310
Indeno[1,2,3,*c,d*]pyrene	X	X	WSLH	SW846, 8310

[1]Both laboratories are certified by the Wisconsin Department of Natural Resources and USEPA and have taken part in USGS inter-laboratory verification round-robins.

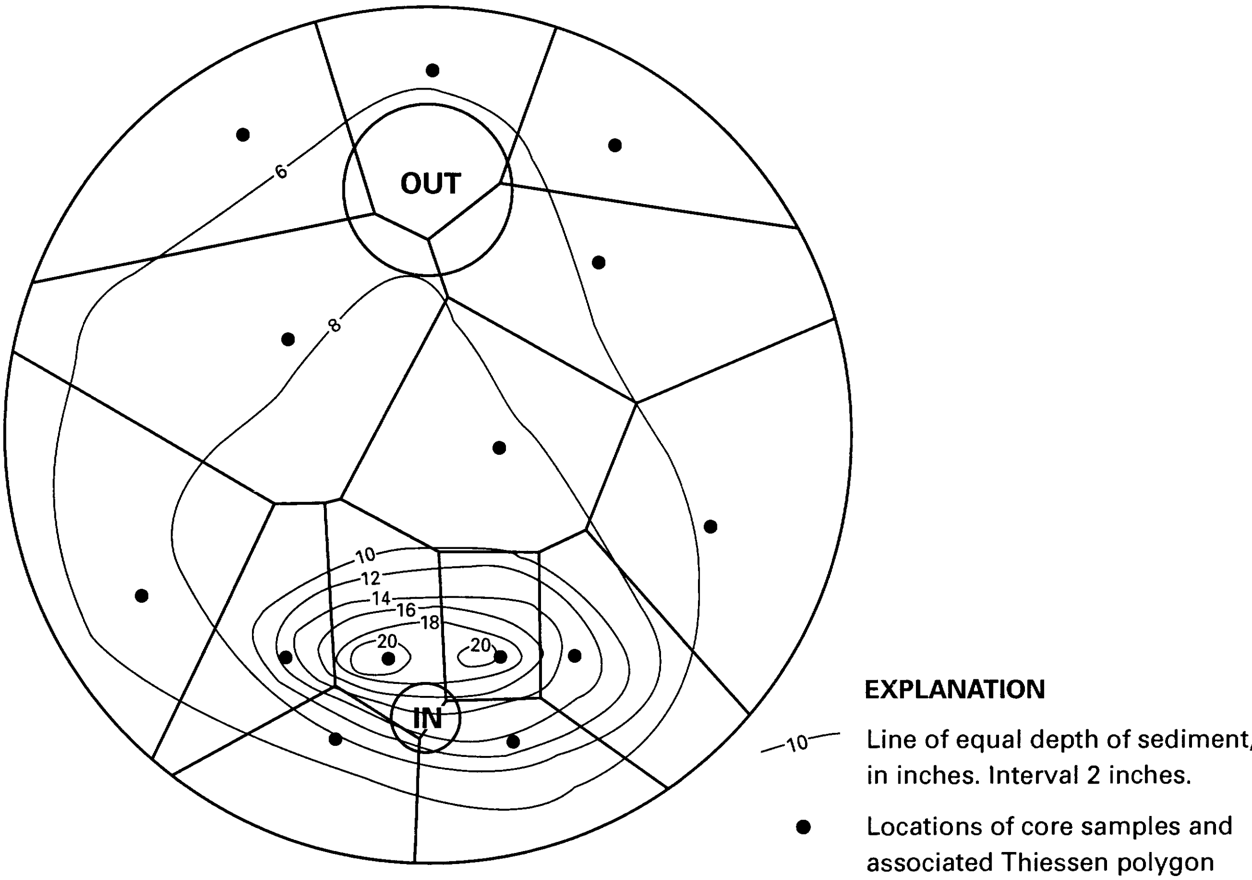


Figure 4. Map showing the depth of retained sediment in the treatment chamber, the location of core samples, and the Thiessen polygon areas of the cores represented.

ments were made to determine the amount and composition of solids in the treatment chamber. To determine the amount of sediment remaining in the treatment chamber, depth measurements were made at several points to create, in effect, a contour map of the sediment. Next, 14 sediment core samples were collected. Thiessen polygons were used to determine the area on the contour map that the cores represented (Chow and others, 1988). By combining the contour map with the Thiessen polygons, the volume of sediment that each core represented was calculated (fig. 4). After the wet volume of each core sample was determined, the cores were individually dried and weighed. To determine the total mass of sediment in the treatment chamber (536 kg), the dry-sediment mass to wet-sediment volume ratio of each core was applied to the sediment volume that each core represented (from Thiessen polygons).

After drying, each core sample was sieved and divided into size fractions of <25 µm, 25–63 µm, 63–250 µm, and >250 µm; each fraction was weighed. Half the mass from each size fraction from all cores was composited into one sample. A Toxicity Characteristics Leachate Procedure (TCLP) analysis on this composite sample was done at the Soils and Engineering Service (SES) laboratory in Madison to determine disposal restrictions. The remaining sample masses were analyzed by size fraction at the SES laboratory for seven constituents (table 3). Because the mass in the <25 µm fraction was insufficient for the required analyses, that fraction was combined with the 25–63 µm fraction to yield a <63 µm fraction. Other than sediment, no comparison was made of constituent loads retained in the treatment chamber to the estimated loads retained based on the water sampling because analytical results for all constituents were available for only 15 of the 45 events.

Quality Control

Quality-control (QC) samples were collected using methods detailed in Corsi and others (1995). Three

Table 3. Type of analysis performed at the Soils and Engineering Service laboratory[1] on sediment core samples from the Madison, Wis., stormwater treatment study

[X, analysis performed; --, analysis not performed; µm, micrometer; TCLP, Toxicity Characteristics Leachate Procedure; SW846 (USEPA 1986); EPA (Kopp and McKee 1979);]

Constituent	Size fraction			Composite	Method
	<63 µm	63–250 µm	>250 µm		
Total cadmium	X	X	X	--	SW846, 6010
Total copper	X	X	X	--	SW846, 6010
Total lead	X	X	X	--	SW846, 6010
Total zinc	X	X	X	--	SW846, 6010
Total phosphorus	X	X	X	--	EPA 365.1
Total polycyclic aromatic hydrocarbons	X	X	X	--	SW846, 8207B
Organic carbon	X	X	X	--	
TCLP (toxicity)	--	--	--	X	SW846, 6010 & 7471

[1]State of Wisconsin laboratory certification 999959180

blank samples collected during the monitoring period were analyzed for the same constituents as the runoff samples (table 2) and were used to evaluate the integrity of the runoff samples. The blank samples also served to indicate whether the event samples were contaminated and to identify possible sources of contamination.

RESULTS OF THE EVALUATION

Precipitation Data Collected at the Site

Precipitation data collected at the site was compared to National Oceanic and Atmospheric Administration data collected at the Dane County Regional Airport. The results and comparisons are listed in tables 4 and 5.

When the precipitation data from the Dane County Regional Airport (DCRA) is compared to the data collected at the site, the total monthly precipitation amounts at the monitoring site are lower than those at the DCRA in all instances. This is an indication that the raingage at the monitoring site was biased to the low side; in other words, it was recording less precipitation than actually occurred. Another observation made from looking at the monthly data is that the discrepancy between the DCRA and the site is largest during the winter months of December through February. Overall, the total precipitation during the period of the study was about 78 percent of normal at the DCRA and 52 percent at the monitoring site. As noted, however, the rainfall at the site is probably biased on the low side.

Stormwater Flow through the Unit

During the two-month equipment-testing period, it became apparent that the two methods of measuring flow—Doppler probe at the inlet and electromagnetic probe at the outlet—were giving different values for the same flow rates. During periods when no bypass flow is occurring, inlet flow must equal outlet flow, but this was not reflected in output from the different meters. This discrepancy did not affect the flow-composite sampling because the inlet and outlet samplers were triggered independently and the difference in measured flow rates was accounted for. However, an accurate determination of flow is essential for reliable mass balance results. Several steps were taken to achieve the most accurate flow estimate possible.

Velocity data from the Doppler probe frequently were suspect; stage data, on the other hand, appeared reliable for most periods. Therefore, a stage-discharge relation was determined at the inlet stage measurement point to eliminate the need for using unreliable velocity data. The stage-discharge relation was developed by eliminating periods in which the velocity data were questionable and applying a best-fit curve through a stage-discharge scatterplot of the remaining data. To increase the accuracy of the rating, dye-dilution samples (Kilpatrick and Cobb, 1985) were collected for a few small events from May through July 1997. The results of the dye-dilution samples confirmed the rating at low stages. No dye-dilution discharge values were obtained for higher stages, so the rating values were accepted as they were.

Table 4. Long-term monthly mean precipitation in inches at Dane County Regional Airport (DCRA) and the observed precipitation at the DCRA and the monitoring site during the August 1996–April 1997 study period in Madison, Wis.

Month	Long-term mean precipitation at DCRA	Precipitation during study period		Percent of long-term mean precipitation		Percent difference between DCRA and monitoring site precipitation
		DCRA	Monitoring site	DCRA	Monitoring site	
August	4.04	1.84	1.39	46	34	28
September	3.37	1.07	.97	32	29	10
October	2.17	3.14	2.93	145	135	7
November	2.09	1.01	.72	48	34	34
December	1.84	1.27	.59	69	32	73
January	1.07	1.24	.44	116	41	95
February	1.08	2.52	1.34	233	124	61
March	2.17	1.54	.95	71	44	47
April	2.86	2.50	1.51	87	53	49
Total	20.69	16.13	10.84	78	52	39

Table 5. Long-term monthly mean snowfall in inches at Dane County Regional Airport (DCRA) and the observed snowfall at the DCRA during the August 1996–April 1997 study period in Madison, Wis.

Month	Long-term mean snowfall at DCRA	Snowfall during study period	Percent of long-term mean snowfall
August	0	0	100
September	0	0	100
October	0.2	0	0
November	3.4	5.9	174
December	12.2	6.7	55
January	9.9	13.1	132
February	7.1	14.4	203
March	7.9	2.7	34
April	2.6	7.1	273
May	.1	.1	100
Total	43.4	50.0	115

To calculate the discharge bypassing the treatment chamber, another rating was developed at the outlet because the inlet stage-discharge rating does not specify the amount passing through the treatment chamber and the amount bypassing. To develop this rating, data from the outlet (electromagnetic probe) during periods of no bypass flow were evaluated for reliability, and those data judged to be reliable were adjusted by use of a correction factor applied to bring them into agreement with the rated data. Outlet data were then evaluated for periods when bypass flow was occurring, and unreliable data were eliminated. The correction factor was applied to the remaining data from bypass periods and an estimated stage-discharge rating was developed using this corrected data by applying a best-fit curve through the data. This estimated rating was used to calculate the flow through the treatment tank once bypass flow began. The difference between the discharges from the inlet rating and the outlet rating was the amount of water bypassing the treatment chamber (fig. 5).

According to the flow data sets, more water passed through the treatment device than the precipitation events should have produced (precipitation depth * drainage area was less than the runoff volume), which indicates errors in either the precipitation measurements or in the flow measurements (table 6). As previously noted, there appeared to be a negative bias in the precipitation data, but it is also likely that the flow measurements are in error because of the complexity involved in their determination. However, accurate flow determination does not affect the calculations of pollutant removal efficiency but only the calculations of solids mass balance. This is true because the flow into the treatment chamber must equal the flow out of the treatment chamber as long as no bypass flow is occuring. During these periods, the efficiencies are solely dependent on the concentrations at the inlet and outlet. The solids mass balance is affected because runoff volume is used to calculate the mass of solids passing through and being retained by the treatment chamber, but the runoff volume does not affect the event mean concentrations, which determine the removal efficiencies.

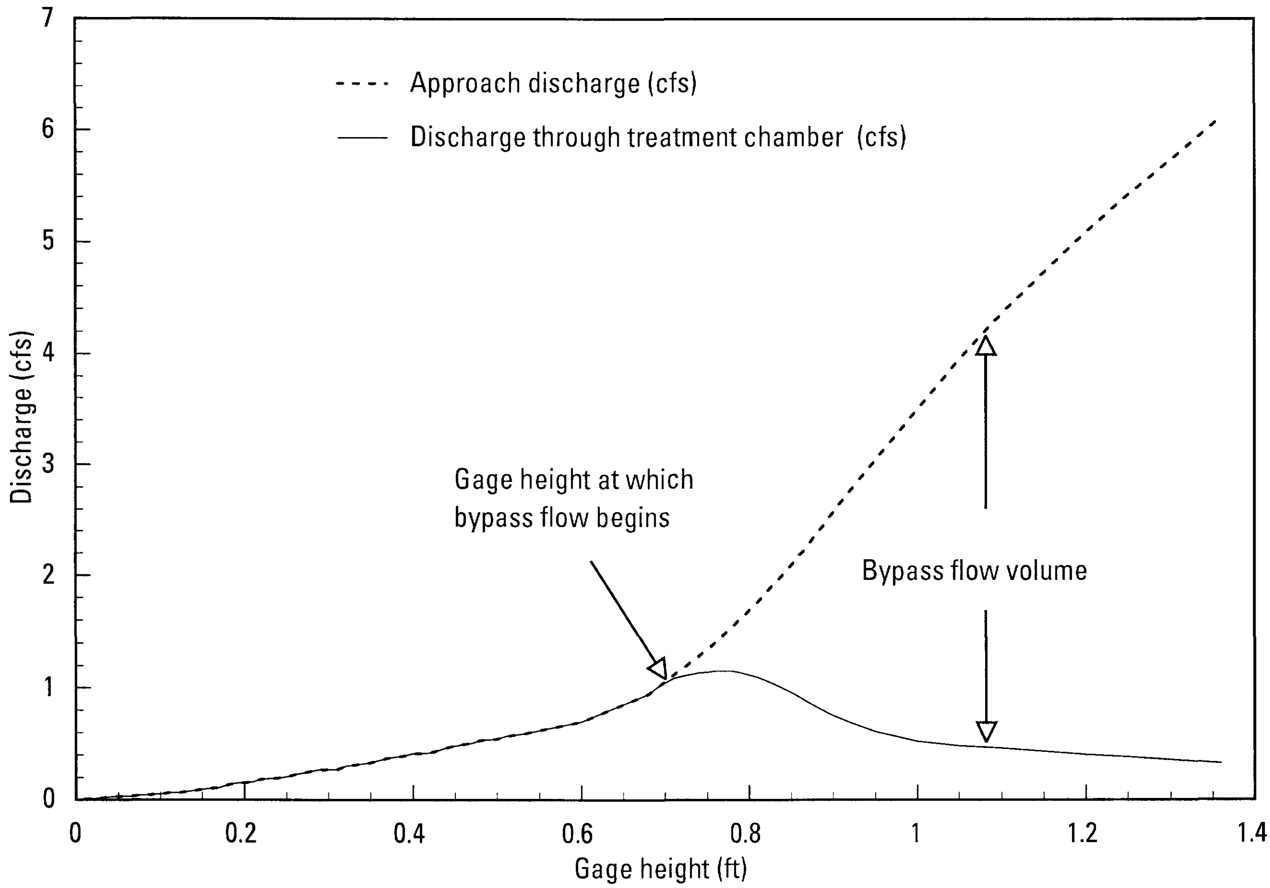


Figure 5. Relation of gage height to discharge in stormwater treatment unit. (Bypass flow volume is the difference between the approach volume and the treatment chamber volume.)

The volume of runoff passing through the treatment chamber or passing through the bypass chamber during the monitoring period compares favorably with values found in product literature for the unit (Stormceptor Corporation, 1997), although a discrepancy existed between when the flow actually began to bypass the treatment chamber and when the literature states that bypass should begin. At 1.1 ft^3/s (~500 gal/min), water began to bypass the treatment chamber; this rate is less than the 800 gal/min listed in the product literature. However, the downstream discharge pipe was at a slightly higher elevation than the treatment-chamber outlet—an installation error—and this misalignment may have caused the discrepancy. If the unit had been installed properly, the bypass chamber should have been free of water during periods of no flow; but because of this condition, about 2 in. of standing water was in the bypass chamber during periods of no flow.

Variability in Concentration of Stormwater Constituents

During compilation of the QC data results, it became apparent that the extremely high concentrations of dissolved solids, which included very high levels of chloride, interfered with analyses of nitrite plus nitrate (NO_2+NO_3) and total suspended solids (TSS). As a result of this observation, the NO_2+NO_3 data were judged unreliable after event 9, when the chloride concentrations in the water samples increased dramatically. Possibly, the high level of chloride in those samples caused very large peaks on the analytical detector that, in effect, masked any NO_2+NO_3 peaks that may have occurred on the detector.

TSS was also affected as dissolved solids (DS) increased, as indicated by the increase in duplicate analysis variability in the pump-down data (appendix 1). Possibly, the high DS concentrations required a more

Table 6. Statistics for runoff events during the Madison, Wis., stormwater treatment study, August 1996–May 1997

[ft^3, cubic feet; *, runoff is at least partially snowmelt; boxed dates, runoff samples from these periods were composited and analyzed as a single event; --, percent runoff was not calculated because of the snowfall/snowmelt nature of the event; XXX, unsampled runoff event]

Event	Total precipitation (inches)	Onset and end of event[1] (date and 24-hour time)		Runoff volume (ft^3)			Percent runoff[2]
		Onset	End	Approaching the unit	Through the treatment chamber	Bypassing the treatment chamber	
1	0.54	8/5/96 16:11	8/6/96 7:01	5989	5381	608	71
2	.11	8/7/96 5:23	8/7/96 6:00	1151	982	169	67
3	.02	8/19/96 14:00	8/19/96 14:19	96	96	0	31
4	.45	8/19/96 18:50	8/20/96 0:12	5170	2915	2255	74
5	.25	8/21/96 15:09	8/21/96 18:07	3184	2486	698	82
6	.10	9/8/96 14:11	9/8/96 16:00	1064	1064	0	68
7	.14	9/20/96 8:41	9/20/96 11:36	1877	1877	0	86
8	.16	9/23/96 20:17	9/23/96 23:44	1975	1975	0	79
9	.56	9/26/96 2:49	9/27/96 1:12	9356	9356	0	107
XXX	.18	10/6/96 21:17	10/6/96 23:36	2312	2048	264	82
10	.89	10/16/96 23:23	10/17/96 5:01	13607	6863	6744	98
11	.03	10/21/96 18:00	10/21/96 18:32	223	223	0	48
12	.49	10/22/96 15:18	10/23/96 1:49	9147	8369	778	120
13	1.31	10/29/96 8:54	10/29/96 19:10	27825	20782	7043	136
XXX	.02	11/4/96 8:22	11/4/96 8:45	110	110	0	35
14	.08	11/6/96 10:13	11/6/96 11:08	1093	1093	0	88
15	.11	11/17/96 1:33	11/17/96 7:24	1419	1419	0	83
XXX	.12*	11/21/96 9:00	11/21/96 12:00	706	706	0	--
XXX	.08*	11/23/96 12:00	11/23/96 13:29	328	328	0	--
XXX	*	11/26/96 21:00	11/27/96 0:00	819	819	0	--
XXX	*	11/27/96 8:00	11/27/96 15:00	1617	1617	0	--
XXX	.03*	11/28/96 18:00	11/29/96 2:00	1510	1510	0	--
XXX	.28*	11/29/96 7:43	11/30/96 4:03	6820	6820	0	--
16	.11*	12/5/96 10:25	12/5/96 13:05	699	699	0	--
XXX	*	12/6/96 11:44	12/6/96 13:18	317	317	0	--
XXX	*	12/7/96 12:27	12/7/96 13:36	283	283	0	--
17	*	12/10/96 11:59	12/10/96 12:29	122	122	0	--
XXX	*	12/13/96 13:06	12/13/96 13:40	129	129	0	--
18	.28*	12/14/96 19:47	12/15/96 6:27	6415	6090	325	--
19	.06*	1/1/97 10:24	1/2/97 12:42	2827	2827	0	--
20	*	1/2/97 12:43	1/2/97 17:48	1996	1996	0	--
21	.35*	1/4/97 3:52	1/4/97 18:00	9899	9558	341	--
22	.01*	1/20/97 10:47	1/20/97 13:56	922	922	0	--
23	.04*	1/21/97 15:42	1/22/97 4:41	5056	5056	0	--
24	*	1/24/97 15:05	1/25/97 14:58	164	164	0	--
	*	1/27/97 10:58	1/27/97 12:15	250	250	0	--
25	*	1/30/97 12:06	1/30/97 14:51	859	859	0	--
26	.20*	1/31/97 10:07	1/31/97 16:43	2700	2700	0	--
27	*	2/1/97 10:47	2/1/97 11:00	62	62	0	--
	*	2/2/97 10:57	2/2/97 12:32	268	268	0	--
28	*	2/4/97 3:59	2/4/97 4:33	171	171	0	--
	*	2/4/97 15:47	2/5/97 14:35	960	960	0	--
29	.17*	2/8/97 11:13	2/8/97 13:26	231	231	0	--

Table 6. Statistics for runoff events during the Madison, Wis., stormwater treatment study, August 1996–May 1997—Continued

Event	Total precipitation (inches)	Onset and end of event[1] (date and 24-hour time)		Runoff volume (ft^3)			Percent runoff[2]
		Onset	End	Approaching the unit	Through the treatment chamber	Bypassing the treatment chamber	
30	0.02*	2/12/97 10:08	2/12/97 11:41	117	117	0	--
	*	2/13/97 13:05	2/13/97 13:40	151	151	0	--
31	*	2/15/97 12:09	2/15/97 12:57	239	239	0	--
	*	2/16/97 11:18	2/16/97 14:32	453	453	0	--
	*	2/17/97 11:03	2/17/97 11:21	86	86	0	--
32	.02*	2/17/97 11:21	2/17/97 15:54	983	983	0	--
	*	2/18/97 8:55	2/18/97 9:39	196	196	0	--
33	*	2/18/97 9:40	2/19/97 5:00	5963	5963	0	--
34	.86*	2/20/97 15:00	2/21/97 16:06	18372	18372	0	--
35	.21*	2/27/97 7:32	2/27/97 12:49	1692	1692	0	--
36	.12*	2/28/97 22:49	3/1/97 15:26	5717	5717	0	--
XXX	.39*	3/9/97 5:58	3/9/97 10:18	7967	7967	114	--
37	.30*	3/24/97 20:25	3/25/97 2:27	5868	5868	0	--
38	.07	3/28/97 6:51	3/28/97 16:55	858	858	0	79
	.01	3/30/97 14:46	3/30/97 14:56	53	53	0	34
	.04	3/30/97 17:49	3/30/97 19:04	472	472	0	76
39	.03	4/4/97 20:02	4/5/97 1:43	314	314	0	67
40	.03	4/5/97 10:17	4/5/97 11:03	396	396	0	85
	.08	4/5/97 17:13	4/5/97 19:24	1911	1632	279	153
	.03	4/6/97 6:52	4/6/97 8:25	765	765	0	163
41	.08*	4/11/97 8:51	4/12/97 18:26	8274	8274	0	--
42	.03*	4/12/97 20:58	4/13/97 17:58	4875	4875	0	--
43	*	4/14/97 10:31	4/14/97 11:58	310	310	0	--
XXX	*	4/17/97 10:23	4/17/97 10:29	29	29	0	--
XXX	.09	4/18/97 21:41	4/19/97 6:57	1228	1228	0	87
XXX	.23	4/20/97 15:30	4/20/97 21:00	4877	4475	402	136
44	.05	4/23/97 22:53	4/24/97 01:41	1139	1139	0	146
45	.93	4/30/97 14:12	5/1/97 5:30	23343	20799	2544	161
			sum	228,376	205,813	22,563	

[1]Based on runoff periods at the flow measurement locations.

[2]Percent runoff was calculated as event runoff volume/precipitation volume.

thorough filter rinsing than was done, which caused TSS analytical results to be higher than the actual sample concentration. Judging from the variability in sample replicate analyses, this was a problem only when the TSS concentrations were low and the DS concentrations were high. These conditions were limited to the pump-down samples; thus, the error associated with the pump-down TSS is higher than the error associated with TSS in runoff samples, and the values reported for TSS during the pump down are probably higher than they should be.

In March 1997, the City of Madison Department of Public Health laboratory changed the method of metals analysis. QC samples indicated a problem with the metals analyses in the first two event samples after the method change (events 37 and 41). Therefore, the metals analyses for samples 37 and 41 were discarded. However, the problem appeared to be eliminated by event 45.

For 15 events, no water samples were collected because of equipment malfunctions, so solids concentrations were estimated. These 15 events are in addition to the 45 monitored events. Solids concentration estimates were needed from these events to perform the solids mass balance analysis, but these estimates were not used in the efficiency calculations. Estimates were made by averaging the concentrations from events that were within 6 weeks of the unmonitored event and had comparable flow volumes. Six weeks was selected as a suitable time period to estimate concentration data because data that were too far separated in time from the period being estimated was not desirable and six weeks generally provided a few data points to work with.

For two events, an outlet sample was collected but not an inlet sample, and for two other events, an inlet sample was collected but not an outlet sample. For these events, concentration estimates were made by averaging the data from other events that were close in time and similar in flow characteristics (like the completely unmonitored events) or by using either the inlet or outlet data from that event and making the estimate. Data were also estimated for one bypass sample by averaging bypass concentrations from events that were within 6 weeks of the event.

The concentration of solids in the bypass flow was much higher than the event mean concentrations. These samples were collected only during peak runoff conditions that would likely be transporting a much higher load of sediment. Concentration data, including estimated concentrations, are found in appendixes 2–5.

Efficiency of the Unit in Removing Stormwater Constituents

Efficiency of the Treatment Chamber

Treatment-chamber efficiencies for individual events were calculated by subtracting the outlet load from the inlet load and dividing the difference by the inlet load ((IN-OUT)/IN). The efficiency of the treatment chamber for the entire monitoring period was calculated for solids by summing all the individual inlet and outlet loads and dividing the difference by the summed inlet load ((ΣIN-ΣOUT)/ΣIN). For events where either the inlet-load or outlet-load data were missing, the event load was not included in the summed loads.

The following equations detail the load calculations:

1. Outlet load = Q*C
   where Q is volume of water passing through the treatment chamber and
   C is outlet event mean concentration

2. Inlet load = upstream load - bypass load

3. Upstream load = Q*C
   where Q is upstreamwater volume and
   C is upstream event mean concentration

4. Downstream load = bypass load + outlet load

5. Solids and phosphorus bypass load = Q*C
   where Q is bypass volume of water and
   C is bypass concentration

6. other constituent bypass load = Q*C
   where Q is bypass volume of water and
   C is upstream event mean concentration

In calculating the bypass load this way, one assumes that the concentration of water bypassing the treatment chamber is the same as the event mean concentration (except for solids and phosphorus), an assumption that may not be accurate because bypass flows generally occur only during peaks in the hydrograph. Because the bypass samples had much higher TSS concentrations than the upstream event mean concentrations, the bypass loads probably represent minimum load estimates. Individual event treatment chamber efficiencies are found in appendixes 6–11.

Overall Efficiency of the Unit

The efficiency of the stormwater unit at treating all the runoff (that is, the water that goes through the treatment chamber and the water that bypasses the treatment chamber) also was calculated. This was determined by comparing the constituent loads in the pipe upstream from the unit to the loads in the pipe downstream from the unit. The loads downstream from the unit were calculated by summing the load that exited the treatment chamber (the outlet load) with the load that bypassed the treatment chamber (the bypass load). The overall efficiency of the unit (appendixes 12–16) will be lower than for the treatment-chamber efficiency alone for all events where bypass flow occurs, and hence for the entire monitoring period. The only exception to this is when there is a negative efficiency; in these cases, the

Table 7. Constituent loads upstream and downstream and at the inlet to and outlet from the treatment chamber of the stormwater treatment unit and removal efficiencies for the treatment chamber and overall unit

[g, gram; kg, kilogram; BOD, biological oxygen demand; COD, chemical oxygen demand; TOC, total organic carbon; DOC, dissolved organic carbon]

Constituent	Treatment chamber			Overall unit		
	Load in	Load out	Reduction efficiency (percent)	Upstream load	Downstream load	Reduction efficiency (percent)
Total suspended solids (kg)	1,258	943	25	1,504	1,189	21
Dissolved solids (kg)	29,743	36,022	-21	30,043	36,323	-21
Total phosphorus (g)	1,435	1,162	19	1,598	1,326	17
Dissolved phosphorus (g)	394	310	21	487	402	17
Total cadmium (g)	3.2	2.3	30	3.5	2.6	27
Dissolved cadmium (g)	1.2	1.2	-4	1.2	1.3	-4
Total copper (g)	66.8	46.8	30	80.7	60.7	25
Dissolved copper (g)	8.8	9.9	-12	11.0	12.1	-10
Total lead (g)	104.4	75.0	28	125.0	95.6	24
Dissolved lead (g)	2.1	1.9	10	2.1	1.9	10
Total zinc (g)	589.8	464.6	21	727.7	602.5	17
Dissolved zinc (g)	96.6	92.0	5	115.4	110.8	4
Total BOD (kg)	44	37	16	50	43	14
Dissolved BOD (kg)	32	30	5	39	37	4
Total COD (kg)	257	202	21	278	223	20
Dissolved COD (kg)	107	122	-14	115	130	-13
$NO_2 + NO_3$ (g)	269	254	6	297	281	5
Ammonia (g)	1,652	1,346	19	1,898	1,592	16
Chloride (kg)	6,066	7,684	-27	6,417	8,036	-25
Alkalinity (kg)	160	140	13	174	154	11
Hardness (kg)	706	228	68	771	293	62
TOC (kg)	47.6	46.5	2	57.3	56.2	2
DOC (kg)	40.8	40.7	0	49.2	49.1	0
Total polycyclic aromatic hydrocarbons (g)	54.0	32.7	39	62.7	41.5	34

overall efficiency will be greater than the treatment-chamber efficiency (table 7).

The overall TSS removal efficiency of the unit (upstream compared to downstream) varied from event to event. An exponential best-fit curve was applied through a scatterplot of TSS removal as a function of peak discharge (fig. 6). Events for which a concentration had to be estimated were not plotted. The five round points (low peak flow and low removal) were not included in the curve fit because, presumably, they were abberations that obscured the underlying relation between peak flow and efficiency. These points were not included in the curve because the curve is used only to illustrate the relation between peak flow and efficiency and is not defined or used for any further calculations. These points were included in all other parts of the analysis.

From figure 6, it appears that the average removal of TSS by the unit should be higher than the 21 percent calculated. For most events it is; however, the large events reduce the overall effectiveness of the unit because a large percentage of the solids load is transported during those periods. When the data were grouped into events with peak discharges less than or equal to 1 cubic foot per second (cfs) and events with peak discharges greater than 1 cfs, the group with peak discharges less than or equal to 1 cfs (34 events) had an overall TSS removal efficiency of 41 percent and

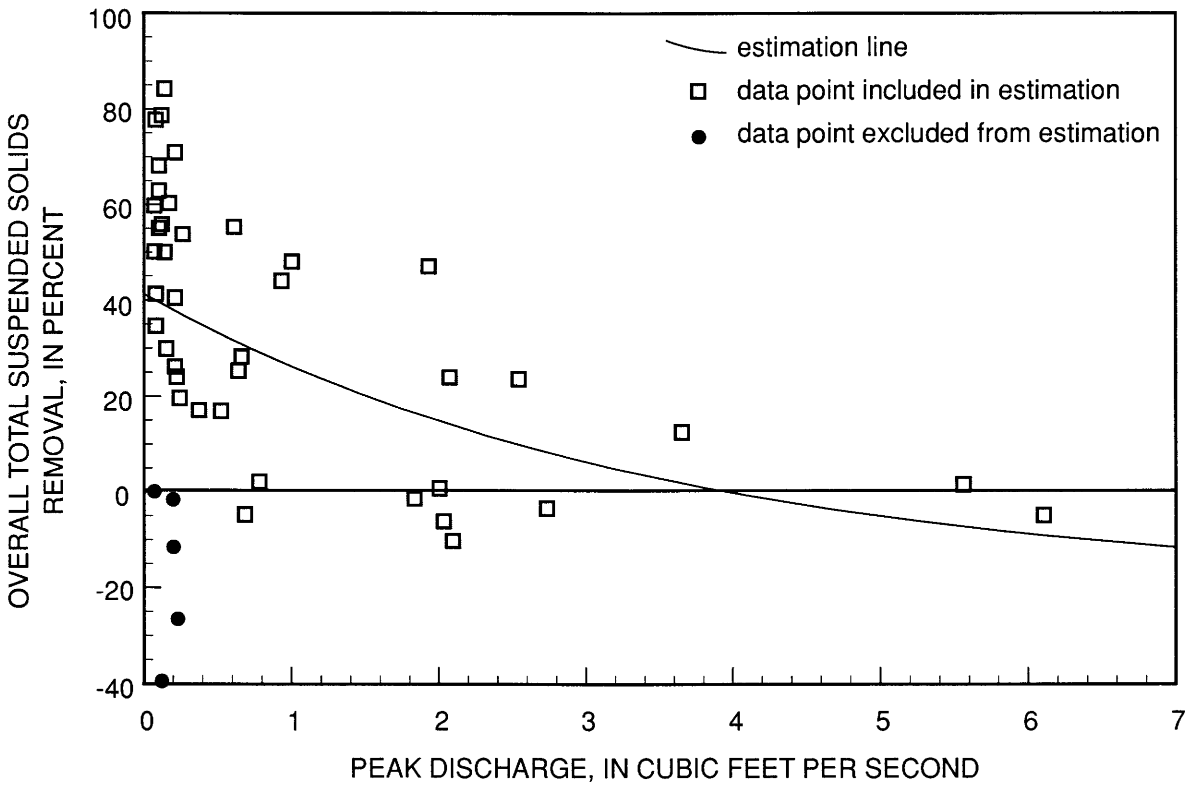


Figure 6. Removal efficiency of suspended solids as a function of peak discharge for the treatment unit as a whole in Madison, Wis., study.

accounted for 738 kg of the upstream load. The group with peak discharges greater than 1 cfs (11 events) had an overall TSS removal efficiency of 1 percent and accounted for 766 kg of the upstream load.

The removal efficiencies seen in this study are lower than those estimated in earlier studies by Bryant (1995), Weatherbe and others (1995), and investigators in Markham, Ontario (Stormceptor Corporation, 1996). The removal results from this study are comparable to a modeling study performed by Marshall and others (1994) and those of a field study which found average suspended solids removals of 17 percent in 1994 and 51 percent in 1995 (Labatiuk and others, 1997). Previous field studies that looked at inlet and outlet concentrations did not collect data and runoff samples from nearly as many events as this study.

The overall unit efficiencies could be affected by the estimates of volume bypassing the treatment chamber. Comparisons of treatment-chamber efficiencies with overall unit efficiencies for events where bypass flow occurred shows little difference between them however, an indication that the difference between inlet and outlet concentrations is still the dominant factor in determining efficiencies.

Material Retained in the Treatment Chamber

At the conclusion of the monitoring period, plugs were inserted into the inlet and outlet of the treatment chamber to prevent any more material from accumulating in the tank and to let sediment in the chamber thoroughly settle. Three weeks later, the plugs were removed, the water was pumped out of the chamber, and water samples were collected using a submersible pump. The solids loads pumped out of the treatment chamber were 741 kg dissolved solids and 1.3 kg suspended solids. Solids concentrations from the pump-down water are listed in appendix 17.

The amount of solids retained by the treatment chamber estimated by using the water sampling mass balance was 405 kg. This includes an estimated load of 90 kg for the 15 unmonitored events (appendix 18). This estimate (405 kg) was 24 percent lower than the estimate made from direct measurements of the material

(536 kg) after the chamber was pumped out. This could be because the automatic samplers do not collect the heavier, larger sand-sized particles (bedload) in the water effectively. If this is the case, the efficiency calculations are probably slightly underestimated.

If the 536 kg inlet solids mass were used for computation, the maximum treatment chamber efficiency would be 33 percent. Assuming that the entire difference between the predicted sediment mass in the tank and the actual mass is due to unsampled bedload, then the bedload represents about 8 percent of the total suspended solids mass in the water.

The results of chemical analysis of core material are presented in table 8. The concentrations of lead and polycyclic aromatic hydrocarbons and the presence of benzo(*a*)anthracene, a known carcinogen, indicate that sediment collected by this and similar units may be subject to special disposal restrictions. The concentrations of pollutants in the retained sediment from this study will almost certainly vary from concentrations at other sites depending on the land use in the drainage area.

Particle-size distribution analyses were done on stormwater samples from the 15 events for which the complete set of chemical constituents was determined. The UAB stormwater lab did the particle-size analysis using a Coulter counter. The Coulter counter measures the volume of particles in various size fractions, not the mass or number of particles in each fraction (table 9).

From the particle-size statistics, it appears that the stormwater unit decreased the proportional volume of particles between 25.75 and 250 μm, and the proportional volume of particles less than 25.75 μm increased slightly as a result.

Results from the Coulter counter method indicate that almost no sand (>63μm) was in the runoff samples, contrary to visual observations of the samples or sieve results on the retained material (table 10); thus, the Coulter counter method appears to underestimate the amount of sand in the samples. Other studies comparing particle-size distributions determined using the Coulter counter and standard USGS sedigraph techniques on split water samples support this finding (David Owens, U.S. Geological Survey, oral commun., 1998).

The particle-size distribution of sediment retained in the treatment chamber indicates a larger percentage of large particles and a smaller percentage of small particles than was noted in previous studies (Bryant and others, 1995; Weatherbe and others, 1995). However, the percentages were comparable to one of the three sites that Labatiuk and others (1997) tested and the modeling results of Marshall and others (1994).

Microtoxicity

The microtoxicity test uses the amount of light produced by fluorescing bacteria to determine bacterial survival in a water sample. A toxic sample will emit less fluorescent light than a laboratory control sample because a certain amount of the fluorescent bacteria will die. As the toxicity of a sample increases, the light reading decreases and the "percent effect" increases (more fully described in the American Society for Testing and Materials, 1998, standard method D 5660-96). The stormwater treatment unit did not affect the microtoxicity of the runoff water as measured by this test (appendix 19).

SUMMARY AND CONCLUSIONS

An underground stormwater treatment unit consisting of an inlet, a treatment chamber, an outlet, and a high-flow bypass was installed in a storm sewer system in Madison, Wis., that collects runoff from a city maintenance yard. According to sizing guidelines in product literature, this model should treat between 82 to 93 percent of the annual flow coming off this area, resulting in approximately 80 percent suspended solids removal. Paired sampling was used to measure the efficiency of the device at reducing stormwater pollutants.

From August 1996 until May 1997, flow measurements and water-quality samples were collected at the inlet to, outlet from, and bypass around the treatment chamber of the device. Using these monitoring data, efficiency of the unit at removing various pollutants was estimated. At the end of the monitoring period, the amount of material retained in the treatment chamber was measured and analyzed. These monitoring results were compared to results from previous evaluations of similar units.

About 90 percent of the runoff water from the 4.3-acre basin was treated by the unit. At a flow rate of approximately 500 gal/min, some of the flow began to bypass the treatment chamber. This bypass flow rate was lower than the rate listed in product literature; possibly because of nonstandard installation conditions.

A 24-percent difference between the estimated amount (405 kg) and the measured amount (536 kg) of retained material in the treatment chamber may be

Table 8. Chemical analysis results of materials retained in the stormwater-unit treatment chamber

[mg/kg, milligrams per kilogram; µm, micrometer; µg/kg, micrograms per kilogram; mg/L, milligrams per liter; --, no analysis]

Compound	Concentration (mg/kg), by size fraction			
	>250 µm	63–250 µm	<63 µm	Composite
Total cadmium	<0.02	0.6	1.1	--
Total copper	9.6	36	77	--
Total lead	8.9	42	56	--
Total zinc	59	170	250	--
Total phosphorus	150	300	480	--
Total organic carbon	6.3	8.3	13.1	--
	Concentration (µg/kg), by size fraction			
Benzo[*a*]anthracene	<360	410	590	--
Benzo[*a*]pyrene	<490	<490	<490	--
Benzo[*b*]fluoranthene	<790	<790	<790	--
Benzo[*g,h,i*]perylene	<540	<540	<540	--
Benzo[*k*]fluoranthene	<620	<620	<620	--
Dibenzo[*a,h*]anthracene	<280	<280	<280	--
Indeno[1,2,3-*cd*]pyrene	<350	<350	<350	--
Naphthalene	<210	<210	<210	--
1-methyl naphthalene	<500	<500	<500	--
2-methyl naphthalene	<180	250	480	--
Acenaphthene	<270	<270	<270	--
Acenaphthylene	<180	<180	<180	--
Fluorene	<230	310	490	--
Phenanthrene	1,300	1,800	3,100	--
Anthracene	<400	<400	<400	--
Fluoranthene	890	1,500	1,900	--
Pyrene	2,100	3,100	7,800	--
Chrysene	440	890	1,400	--
Surrogates				
Nitrobenzene-d5	61	41	58	--
2-fluorobiphenyl	79	58	71	--
Terphenyl-d14	103	84	127	--
Toxicity characteristics leachate procedure analysis	Concentration (mg/L) in composite sample			
Arsenic	--	--	--	<.03
Barium	--	--	--	.44
Cadmium	--	--	--	.005
Chromium	--	--	--	.003
Lead	--	--	--	<.02
Mercury	--	--	--	<.0002
Selenium	--	--	--	<.005
Silver	--	--	--	<.0007

Table 9. Coulter counter particle-size statistics for the inlet to and outlet from the stormwater-unit treatment chamber
[µm, micrometer; %, percent]

Size (µm)	Inlet to treatment tank				Outlet from treatment tank			
	Mean (%)	Standard deviation	Maximum (%)	Minimum (%)	Mean (%)	Standard deviation	Maximum (%)	Minimum (%)
<25.75	76.9	10.9	98.6	55.6	82.5	7.1	95.8	70.5
25.75–62.52	18.4	8.3	33.2	1.4	15.2	5.8	24.6	4.2
62.52–250	4.7	5.0	17.7	.0	2.3	3.1	10.9	.0
>250	.0	.0	.0	.0	.0	.0	.0	.0

Table 10. Mass of solids measured in the stormwater-unit chamber in each particle size fraction

Size fraction (micrometers)	Mass (kilograms)
>250	417
63–250	89
<63	29
Total	536

attributed to bedload material that the automatic samplers could not effectively collect. Assuming this, the unsampled bedload was calculated to be 8 percent of the total mass in the untreated runoff water.

On the basis of water-sample data collected over the course of the study, the suspended solids removal efficiency of the treatment chamber was about 25 percent, and the efficiency of the unit as whole was 21 percent. If the retained mass was used to make the estimate, the treatment-chamber efficiency was 33 percent. The efficiency for individual storms varied greatly and in general decreased as peak flow rates increased.

About 19 percent of the total phosphorus was removed from the water that passed through the treatment chamber, and about 17 percent was removed by the unit as a whole. Total metals were reduced about 20–30 percent by both the treatment chamber and by the unit as a whole. Total polycyclic aromatic hydrocarbon (PAH) loads were reduced about 39 percent through the treatment chamber and 34 percent by the unit as a whole; these were some of the most effectively removed constituents. In general, dissolved constituents were unaffected by the unit.

The treatment unit did not appear to have any effect on the toxicity of stormwater samples to bacteria.

The material retained in the treatment chamber had high concentrations of lead and PAH's and may be subject to special disposal restrictions based on the observed lead and PAH concentrations and the presence of benzo(*a*)anthracene. The chemical makeup of the retained material in other similar stormwater treatment units will probably vary depending on the land use of the drainage basin.

The findings from this study on the performance of the stormwater treatment unit are not comprehensive. Many of the conditions at this particular installation (a city maintenance yard) may be unique and could have affected the results, particularly the presence of road sand and salt piles so close to the system inlet. Findings at another monitoring location may be quite different. However, this study is thought to be the most extensive field testing of such a unit to date.

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APPENDIXES 1–19

Appendix 1. Variability in replicate sample analyses for solids in the Madison, Wis., stormwater treatment study, 1996–97

[mg/L, milligrams per liter; in-x, refers to samples collected during the x^{th} event number at the inlet to the treatment chamber of the device; out-x, refers to samples collected during the x^{th} event number at the outlet to the treatment chamber of the device; bypass, refers to samples collected during the x^{th} event number at the bypass around the treatment chamber of the device; --, no analysis; dupe, duplicate sample, superscript 1 indicates that these samples were collected in a different manner and at a later time than the rest of the pumpdown samples]

Sample	Total suspended solids						Dissolved solids					
	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)
in-1	151	166	--	159	10.61	7	228	216	224	223	6.11	3
out-1	154	158	--	156	2.83	2	252	260	--	256	5.66	2
bypass-1	190	202	200	197	6.43	3	194	186	--	190	5.66	3
in-2	172	180	--	176	5.66	3	190	196	--	193	4.24	2
out-2	71	70	--	71	.71	1	164	162	--	163	1.41	1
in-3	132	130	--	131	1.41	1	760	752	--	756	5.66	1
out-3	--	--	--	--	--	--	--	--	--	--	--	---
in-4	288	282	270	280	9.17	3	--	--	--	--	--	--
out-4	150	154	--	152	2.83	2	--	--	--	--	---	--
bypass-4	430	440	--	435	7.07	2	168	164	--	166	2.83	2
in-5	285	264	--	275	14.85	5	166	164	--	165	1.41	1
out-5	158	159	158	158	.58	0	188	188	--	188	.00	0
bypass-5	384	400	--	392	11.31	3	162	170	--	166	5.66	3
in-6	118	118	132	123	8.08	7	1,080	1,072	--	1,076	5.66	1
out-6	56	58	---	57	1.41	2	388	376	--	382	8.49	2
in-7	160	166	172	166	6.00	4	308	308	--	308	.00	0
out-7	94	94	92	93	1.15	1	336	348	--	342	8.49	2
in-8	66	65	63	65	1.53	2	152	152	--	152	.00	0
out-8	54	53	--	54	.71	1	208	208	--	208	.00	0
in-9	144	142	136	141	4.16	3	100	108	--	104	5.66	5
out-9	134	142	--	138	5.66	4	112	108	116	112	4.00	4
in-10	351	378	--	365	19.09	5	1,420	1,428	1,480	1,443	3,2.58	2
out-10	233	229	--	231	2.83	1	1,656	1,636	---	1,646	14.14	1
bypass-10	523	552	--	538	20.51	4	304	284	--	294	14.14	5
in-11	--	--	--	--	--	--	--	--	--	--	--	--
out-11	29	30	31	30	1.00	3	1,240	1,224	--	1,232	11.31	1
in-12	140	146	--	143	4.24	3	688	668	--	678	14.14	2
out-12	93	94	--	94	.71	1	808	808	--	808	.00	0

Appendix 1. Variability in replicate sample analyses for solids in the Madison, Wis., stormwater treatment study, 1996–97—Continued

Sample	Total suspended solids						Dissolved solids					
	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)
bypass-12	457	481	--	469	16.97	4	408	400	--	404	5.66	1
in-13	97	94	103	98	4.58	5	492	504	496	497	6.11	1
out-13	94	90	--	92	2.83	3	532	528	--	530	2.83	1
bypass-13	129	129	--	129	.00	0	412	420	--	416	5.66	1
in-14	--	--	--	--	--	--	4,764	4,768	--	4,766	2.83	0
out-14	--	--	--	--	--	--	5,088	5,088	5,100	5,092	6.93	0
in-15	220	216	212	216	4.00	2	17,692	17,664	--	17,678	19.80	0
out-15	154	156	--	155	1.41	1	12,096	12,116	12,128	12,113	16.17	0
in-16	810	838	--	824	19.80	2	56,132	56,004	--	56,068	90.51	0
out-16	298	310	312	307	7.57	2	44,832	45,068	44,908	44,936	120.47	0
in-17	---	--	--	--	-	-	--	--	--	--	--	--
out-17	80	86	--	83	4.24	5	24,864	24,864	--	24,864	.00	0
in-18	444	448	--	446	2.83	1	3,856	3,860	--	3,858	2.83	0
out-18	276	278	280	278	2.00	1	4,276	4,312	4,316	4,301	22.03	1
bypass-18	1,514	1,464	-	1,489	35.36	2	1,796	1,804	--	1,800	5.66	0
in-19	605	622	600	609	11.53	2	14,548	14,532	14,520	14,533	14.05	0
out-19	311	300	--	306	7.78	3	24,904	24,884	--	24,894	14.14	0
in-20	248	255	--	252	4.95	2	11,264	11,288	--	11,276	16.97	0
out-20	-	---	--	---	--	--	--	--	--	--	---	--
in-21	564	537	--	551	19.09	3	10,328	10,324	--	10,326	2.83	0
out-21	523	538	--	531	10.61	2	11,592	11,532	--	11,562	42.43	0
bypass-21	2,110	2,084	--	2,097	18.38	1	7,540	7,532	--	7,536	5.66	0
in-22	251	269	--	260	12.73	5	45,956	45,944	45,880	45,927	40.86	0
out-22	109	118	117	115	4.93	4	76,632	76,060	--	76,346	404.47	1
in-23	133	137	--	135	2.83	2	17,888	17,876	--	17,882	8.49	0
out-23	174	167	--	171	4.95	3	22,948	22,996	--	22,972	33.94	0
in-24	1,031	1,049	--	1,040	12.73	1	113,876	113,836	-	113,856	28.28	0
out-24	334	331	--	333	2.12	1	95,032	95,088	-	95,060	39.60	0
in-25	1,258	1,260	1,190	1,236	39.85	3	75,340	75,472	75,416	75,409	66.25	0
out-25	242	280	274	265	20.43	8	95,656	95,748	95,048	95,484	380.38	0

Appendix 1. Variability in replicate sample analyses for solids in the Madison, Wis., stormwater treatment study, 1996–97—Continued

Sample	Total suspended solids						Dissolved solids					
	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)
in-26	848	838	882	856	23.07	3	27,570	27,640	27,590	27,600	36.06	0
out-26	345	336	--	341	6.36	2	36,580	36,590	--	36,585	7.07	0
in-27	100	94	--	97	4.24	4	10,560	10,560	--	10,560	.00	0
out-27	59	54	--	57	3.54	6	15,410	15,420	--	15,415	7.07	0
in-28	918	906	--	912	8.49	1	37,290	37,230	--	37,260	42.43	0
out-28	544	561	523	543	19.04	4	37,040	36,450	--	36,745	417.19	1
in-29	374	374	--	374	.00	0	6,910	6,930	--	6,920	14.14	0
out-29	149	152	151	151	1.53	1	15,110	15,070	15,080	15,087	20.82	0
in-30	640	618	--	629	15.56	2	7,530	7,530	7,530	7,530	.00	0
out-30	146	142	136	141	5.03	4	35,420	35,510	--	35,465	63.64	0
in-31	436	434	--	435	1.41	0	8,020	8,030	--	8,025	7.07	0
out-31	108	168	--	138	42.43	31	38,070	38,150	--	38,110	56.57	0
out-31 repeat	128	132	122	127	5.03	4	-	-	--	--	--	-
in-32	595	580	--	588	10.61	2	10,170	10,200	--	10,185	21.21	0
out-32	390	378	--	384	8.49	2	12,020	11,950	--	11,985	49.50	0
in-33	242	268	--	255	18.38	7	9,320	9,320	--	9,320	.00	0
out-33	203	207	--	205	2.83	1	9,860	9,870	--	9,865	7.07	0
in-34	430	432	--	431	1.41	0	9,090	9,110	9,080	9,093	15.28	0
out-34	200	186	--	193	9.90	5	9,340	9,320	--	9,330	14.14	0
in-35	580	630	602	604	25.06	4	20,680	20,650	--	20,665	21.21	0
out-35	454	464	-	459	7.07	2	17,980	17,970	--	17,975	7.07	0
in-36	116	134	124	125	9.02	7	3,270	3,270	--	3,270	.00	0
out-36	134	128	-	131	4.24	3	4,710	4,680	--	4,695	21.21	0
in-37	157	173	169	166	8.33	5	1,192	1,196	1,196	1,195	2.31	0
out-37	128	121	--	125	4.95	4	3,432	3,436	--	3,434	2.83	0
in-38	116	123	122	120	3.79	3	1,732	1,720	1,716	1,723	8.33	0
out-38	136	133	--	135	2.12	2	2,032	2,040	--	2,036	5.66	0
in-39	42	43	--	43	.71	2	1,036	1,040	--	1,038	2.83	0
out-39	60	60	--	60	.00	0	2,404	2,408	--	2,406	2.83	0
in-40	656	664	--	660	5.66	1	464	456	--	460	5.66	1

Appendix 1. Variability in replicate sample analyses for solids in the Madison, Wis., stormwater treatment study, 1996–97—Continued

Sample	Total suspended solids						Dissolved solids					
	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)
out-40	590	640	--	615	35.36	6	3,616	3,628	--	3,622	8.49	0
bypass-40	1,891	1,826	--	1,859	45.96	2	404	412	--	408	5.66	1
in-41	95	93	--	94	1.41	2	6,384	6,376	--	6,380	5.66	0
out-41	79	77	--	78	1.41	2	9,260	9,268	9276	92,68	8.00	0
in-42	59	55	60	58	2.65	5	1,448	1,336	--	1,392	79.20	6
out-42	60	58	--	59	1.41	2	2,812	2,840	--	2,826	19.80	1
in-43	40	50	--	45	7.07	16	2,636	2,632	--	2,634	2.83	0
out-43	45	45	--	45	.00	0	1,984	1,972	--	1,978	8.49	0
in-44	84	92	--	88	5.66	6	1,492	1,484	1,508	1,495	12.22	1
out-44	68	63	64	65	2.65	4	1,432	1,428	--	1,430	2.83	0
in-45	185	176	--	181	6.36	4	676	664	--	670	8.49	1
out-45	169	171	--	170	1.41	1	1,292	1,272	--	1,282	14.14	1
bypass-45	263	253	--	258	7.07	3	596	604	--	600	5.66	1
Distance from bottom of treatment chamber	**Pumpdown samples**											
11.99	50	53	51	51	1.53	3	5828	5812	---	5820	11.31	0
10.51	10	11	--	11	.71	7	5036	5024	5032	5031	6.11	0
9.25	15	20	--	18	3.54	20	16,108	16,056	--	16,082	36.77	0
9.25 (dupe)	19	23	19	20	2.31	11	--	--	--	--	--	-
8.33	22	11	--	17	7.78	47	16,740	16,704	--	16,722	25.46	0
8.33 (dupe)	21	17	--	19	2.83	15	-	--	--	--	--	--
6.84	56	76	--	66	14.14	21	30,588	30,564	--	30,576	16.97	0
6.84 (dupe)	24	44	--	34	14.14	42	--	--	--	---	--	-
6.84 (dupe)	114	103	--	109	7.78	7	--	---	--	-	--	-
5.75	21	24	22	22	1.53	7	14,344	14,332	--	14,338	8.49	0
4.86	90	84	--	87	4.24	5	36,524	36,556	--	36,540	22.63	0
4.23	49	53	--	51	2.83	6	38,788	39,128	--	38,958	240.42	1
3.38	186	58	--	122	90.51	74	67,152	67,568	--	67,360	294.16	0

Appendix 1. Variability in replicate sample analyses for solids in the Madison, Wis., stormwater treatment study, 1996–97—Continued

Distance from bottom of treatment chamber	Total suspended solids						Dissolved solids					
	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)	Replicate 1 (mg/L)	Replicate 2 (mg/L)	Replicate 3 (mg/L)	Average (mg/L)	Standard deviation (mg/L)	Ratio of standard deviation to average (percent)
3.38 (dupe)	94	108	--	101	9.90	10						
3.12	84	106	--	95	15.56	16	49,968	50,032	-	50,000	45.25	0
3.12 (dupe)	102	98	--	100	2.83	3						
2.76	138	149	--	144	7.78	5	103,388	102,864	-	103,126	370.52	0
2.21	92	138	--	115	32.53	28	70,468	70,308	70,480	70,419	96.03	0
2.21 (dupe)	94	116	--	105	15.56	15						
1.83	506	500	--	503	4.24	1	105,136	104,888	-	105,012	175.36	0
1.67	242	238	--	240	2.83	1	104,200	103,984	-	104,092	152.74	0
1.54	184	32	--	108	107.48	100	93,024	92,892	-	92,958	93.34	0
1.54 (dupe)	194	198	224	205	16.29	8						
1.40	84	160	--	122	53.74	44	63,036	62,988	-	63,012	33.94	0
1.40 (dupe)	152	148	--	150	2.83	2						
1.40[1]	142	134	--	138	5.66	4	18,984	18,992	-	18,988	5.66	0
1.40[1] (dupe)	74	82	--	78	5.66	7	20,780	20,784	-	20,782	2.83	0

Appendix 2. Metals concentrations in runoff samples at the inlet to and outlet from the stormwater-unit treatment chamber

[All concentrations in micrograms per liter; --, no concentration available; boxed number means the value is between limit of detection and limit of quantitation; gray cells means lab contamination is suspected]

Sample	Date	Cadmium (µg/L)		Copper (µg/L)		Lead (µg/L)		Zinc (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Inlet									
IN-1	8/6/96	<0.25	0.34	5.3	15.7	<1	15.7	17	130
IN-4	8/20/96	<.25	.93	4.2	39.8	<1	44.2	20	242
IN-7	9/23/96	.67	1.15	23.1	42.9	2.9	22.6	124	314
IN-8	9/25/96	<.25	<.25	9.4	14.7	<1	7.5	43	97
IN-9	9/27/96	<0.25	.29	3.9	17.0	<1	20.0	57	131
IN-10	10/17/96	<.25	.50	6.7	32.1	<1	46.9	49	375
IN-12	10/23/96	<.25	<.25	3.6	14.6	<1	16.4	50	151
IN-13	10/30/96	<.25	<.25	2.3	10.0	<1	17.2	24	121
IN-15	11/17/96	2.12	4.86	6.1	33	9.4	84	--	307
IN-18	12/16/96	1.55	2.67	<1.2	33	<1	90	6.7	320
IN-21	1/5/97	.63	3.67	<1.2	57	<1	84	20	405
IN-23	1/22/97	3.41	3.26	8	22	11	34	126	252
IN-45	5/1/97	.21	1.23	<3.8	21	<1.25	37	23	170
Outlet									
OUT-1	8/6/96	<.25	<.25	6.2	17.3	<1	14.4	25	130
OUT-4	8/20/96	<.25	.30	6.4	16.9	7.4	16.3	37	132
OUT-7	9/23/96	.28	.57	11.2	25.5	3.3	13.9	90	183
OUT-8	9/25/96	<.25	.32	8.7	16.4	2.3	6.8	65	105
OUT-9	9/27/96	<.25	<.25	4.0	14.7	<1	18.7	23	121
OUT-10	10/17/96	<.25	<.25	12.0	24.1	<1	25.6	42	221
OUT-12	10/23/96	<.25	<.25	4.3	11.5	<1	11.9	40	118
OUT-13	10/30/96	<.25	<.25	3.1	10.5	<1	10.3	36	107
OUT-15	11/17/96	2.05	4.07	<1.2	21	12	54	17	239
OUT-18	12/16/96	1.03	1.71	<1.2	16	<1	56	15	222
OUT-21	1/5/97	1.48	2.80	<1.2	42	6.9	71	20	356
OUT-23	1/22/97	3.07	3.93	8	28	8.7	36	122	241
OUT-45	5/1/97	.18	.72	<3.8	6.9	<1.25	26	20	125

Appendix 3. Selected constituent concentrations at inlet, outlet, and bypass in runoff at stormwater runoff monitoring site, Madison, Wis., 1996–97

[-, no analysis; boxed values are estimated concentrations]

Sample	Date	ph	Conductance (μmho/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Biological oxygen demand (mg/L)		Chemical oxygen demand (mg/L)		Chloride (mg/L)	Total suspended solids (mg/L)	Dissolved solids (mg/L)	Ammonia (mg/L)	NO_2 + NO_3 (mg/L)	Phosphorus (mg/L)	
						Dissolved	Total	Dissolved	Total						Dissolved	Total
IN-1	08/06/96	6.94	411	40	45	-	11	37.6	48.5	96.3	158	223	0.46	0.56	0.13	-
IN-2	08/07/96	-	-	-	-	-	-	-	-	-	176	193	-	-	-	-
IN-3	08/19/97	-	-	-	-	-	-	-	-	-	131	756	-	-	-	-
IN-4	08/20/96	6.84	335	46	50	-	10	33.4	97.6	70.3	280	167	.44	.28	.11	-
IN-5	08/22/96	-	-	-	-	-	-	-	-	-	274	165	-	-	-	-
IN-6	09/09/96	-	-	-	-	-	-	-	-	-	123	1,075	-	-	-	-
IN-7	09/23/97	-	-	-	-	-	-	96.3	165	-	166	308	1.19	-	.4	-
IN-8	09/25/96	-	-	-	-	-	20	67.5	201	43.3	65	152	.46	.61	.28	-
IN-9	09/27/96	7.32	-	-	-	10	12	-	-	17.8	141	104	.24	.48	.14	-
IN-10	10/17/96	7.42	-	-	60	19.5	-	-	-	855.9	365	1,443	.41	-	.21	-
IN-11	10/21/96	-	-	-	-	-	-	-	-	-	189	1,575	-	-	-	-
IN-12	10/23/96	7.34	1,327	24	32	8	12	-	-	399	143	678	.52	-	.12	-
IN-13	10/30/96	-	-	20	-	7.5	10	-	-	289.3	98	497	.39	-	.12	-
IN-14	11/07/97	-	-	-	-	-	-	-	-	-	375	4,766	-	-	-	-
IN-15	11/17/96	6.58	29.07	38	150	<18	<9	227	236	11,270.7	216	17,678	1.15	-	.32	-
IN-16	12/06/96	-	-	-	-	-	-	-	-	-	824	56,100	-	-	-	-
IN-17	12/10/96	-	-	-	-	-	-	-	-	-	166	24,900	-	-	-	-
IN-18	12/15/96	7.94	7,026	152	110	7.5	13.6	36.5	170.3	2313	446	3,858	.48	-	.05	-
IN-19	01/02/97	-	-	-	-	-	-	-	-	-	609	14,533	-	-	-	-
IN-20	01/03/97	-	-	-	-	-	-	-	-	-	251	11,276	-	-	-	-
IN-21	01/05/97	8.18	17,803	216	160	7.25	12	61	220.5	6,517.2	551	10,326	1.00	-	.05	-
IN-22	01/22/97	-	-	-	-	-	-	-	-	-	260	45,927	-	-	-	-
IN-23	01/22/97	7.62	29,967	53	254	14.15	29	90.4	194.8	11,037.3	135	17,882	.18	-	.04	-
IN-24	01/26/97	-	-	-	-	-	-	-	-	-	1,040	113,856	-	-	-	-
IN-25	01/31/97	-	-	-	-	-	-	-	-	-	1,236	75,409	-	-	-	-
IN-26	02/03/97	-	-	-	-	-	-	-	-	-	856	27,600	-	-	-	-
IN-27	02/03/97	-	-	-	-	-	-	-	-	-	97	10,560	-	-	-	-
IN-28	02/06/97	-	-	-	-	-	-	-	-	-	912	37,260	-	-	-	-

Appendix 3. Selected constituent concentrations at inlet, outlet, and bypass in runoff at stormwater runoff monitoring site, Madison, Wis., 1996–97—Continued

Sample	Date	ph	Conductance (μmho/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Biological oxygen demand (mg/L)		Chemical oxygen demand (mg/L)		Chloride (mg/L)	Total suspended solids (mg/L)	Dissolved solids (mg/L)	Ammonia (mg/L)	NO_2 + NO_3 (mg/L)	Phosphorus (mg/L)	
						Dissolved	Total	Dissolved	Total						Dissolved	Total
IN-29	02/10/97	-	-	-	-	-	-	-	-	-	374	6,920	-	-	-	-
IN-30	02/13/97	-	-	-	-	-	-	-	-	-	629	7,530	-	-	-	-
IN-31	02/13/97	-	-	-	-	-	-	-	-	-	435	8,025	-	-	-	-
IN-32	02/18/97	-	-	-	-	-	-	-	-	-	587	10,185	-	-	-	-
IN-33	02/19/97	-	-	-	-	-	-	-	-	-	255	93,20	-	-	-	-
IN-34	02/21/97	-	-	-	-	-	-	-	-	-	431	9,093	-	-	-	-
IN-35	02/27/97	-	-	-	-	-	-	-	-	-	604	20,665	-	-	-	-
IN-36	03/01/97	-	-	-	-	-	-	-	-	-	125	3,270	-	-	-	-
IN-37	03/25/97	7.44	2,390	42	-	10	7.5	35.1	73.2	720.6	166	1,195	1.14	-	.08	-
IN-38	03/31/97	-	-	-	-	-	-	-	-	-	120	1,723	-	-	-	-
IN-39	04/05/97	-	-	-	-	-	-	-	-	-	43	1,038	-	-	-	-
IN-40	04/05/97	-	-	-	-	-	-	-	-	-	660	460	-	-	-	-
IN-41	04/13/97	7.46	11,670	44	1066	6.5	7.5	35.8	69.1	4,572.7	94	6,380	.62	-	.06	-
IN-42	04/15/97	-	-	-	-	-	-	-	-	-	58	1,392	-	-	-	-
IN-43	04/15/97	-	-	-	-	-	-	-	-	-	45	2,634	-	-	-	-
IN-44	04/25/97	-	-	-	-	-	-	-	-	-	88	1,495	-	-	-	-
IN-45	05/01/97	7.21	1,283	36	546	18	27	51.7	113.7	373.7	181	670	.34	-	.15	-
								Outlet								
OUT-1	08/06/96	7.05	446	42	60	-	14	46.8	49.8	104	156	256	.49	.69	.11	-
OUT-2	08/07/97	-	-	-	-	-	-	-	-	-	70	163	-	-	-	-
OUT-3	08/19/97	-	-	-	-	-	-	-	-	-	59	311	-	-	-	-
OUT-4	08/20/96	6.93	393	44	80	-	11	51.1	71.7	88	152	218	.23	.38	.08	-
OUT-5	08/22/96	-	-	-	-	-	-	-	-	-	158	188	-	-	-	-
OUT-6	09/09/96	-	-	-	-	-	-	-	-	-	57	382	-	-	-	-
OUT-7	09/23/97	-	-	-	-	-	-	78.3	98.3	-	93	342	1.09	-	.3	-
OUT-8	09/25/96	-	-	-	-	-	16	71.7	96	49.5	54	208	<.2	.3	.09	-
OUT-9	09/27/96	-	-	-	-	7	10	-	-	20.2	138	112	<.2	.38	.08	-
OUT-10	10/17/96	7.08	-	-	60	22	-	-	-	927.5	231	1,646	.64	-	.21	-
OUT-11	10/21/96	-	-	-	-	-	-	-	-	-	30	1,232	-	-	-	-

Appendix 3. Selected constituent concentrations at inlet, outlet, and bypass in runoff at stormwater runoff monitoring site, Madison, Wis., 1996–97—Continued

Sample	Date	ph	Conductance (µmho/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Biological oxygen demand (mg/L)		Chemical oxygen demand (mg/L)		Chloride (mg/L)	Total suspended solids (mg/L)	Dissolved solids (mg/L)	Ammonia (mg/L)	NO_2 + NO_3 (mg/L)	Phosphorus (mg/L)	
						Dissolved	Total	Dissolved	Total						Dissolved	Total
OUT-12	10/23/96	7.22	11,570	26	44	9.3	15	-	-	478	93	808	0.32	-	0.05	-
OUT-13	10/30/96	-	-	20	-	9	9.5	-	-	309.1	92	530	.42	-	.11	-
OUT-14	11/07/96	-	-	-	-	-	-	-	-	-	195	5,092	-	-	-	-
OUT-15	11/17/96	6.84	20.5	68	180	<16	<4	201	296	7,355.7	155	12,113	.79	-	.2	-
OUT-16	12/06/96	-	-	-	-	-	-	-	-	-	307	44,900	-	-	-	-
OUT-17	12/10/96	-	-	-	-	-	-	-	-	-	83	24,900	-	-	-	-
OUT-18	12/15/97	7.77	7,820	76	100	9	13	39.5	139.4	2,648.3	278	4,301	.58	-	.04	-
OUT-19	01/02/97	-	-	-	-	-	-	-	-	-	305	24,894	-	-	-	-
OUT-20	01/03/97	-	-	-	-	-	-	-	-	-	176	11,276	-	-	-	-
OUT-21	01/05/97	-	19,910	184	160	6.5	10	76.5	80.6	7,335.8	531	11,562	1.02	-	.04	-
OUT-22	01/22/97	-	-	-	-	-	-	-	-	-	115	76,346	-	-	-	-
OUT-23	01/22/97	7.68	37,700	68	292	15.5	27	174.3	253.4	14,415	171	22,972	<.2	-	.04	-
OUT-24	01/26/97	-	-	-	-	-	-	-	-	-	333	95,060	-	-	-	-
OUT-25	01/31/97	-	-	-	-	-	-	-	-	-	265	95,484	-	-	-	-
OUT-26	02/03/97	-	-	-	-	-	-	-	-	-	341	36,585	-	-	-	-
OUT-27	02/03/97	-	-	-	-	-	-	-	-	-	57	15,415	-	-	-	-
OUT-28	02/06/97	-	-	-	-	-	-	-	-	-	543	36,745	-	-	-	-
OUT-29	02/10/97	-	-	-	-	-	-	-	-	-	151	15,087	-	-	-	-
OUT-30	02/13/97	-	-	-	-	-	-	-	-	-	141	35,465	-	-	-	-
OUT-31	02/13/97	-	-	-	-	-	-	-	-	-	127	38,110	-	-	-	-
OUT-32	02/18/97	-	-	-	-	-	-	-	-	-	384	11,985	-	-	-	-
OUT-33	02/19/97	-	-	-	-	-	-	-	-	-	205	9,865	-	-	-	-
OUT-34	02/21/97	-	-	-	-	-	-	-	-	-	193	9,330	-	-	-	-
OUT-35	02/27/97	-	-	-	-	-	-	-	-	-	459	17,975	-	-	-	-
OUT-36	03/01/97	-	-	-	-	-	-	-	-	-	131	4,695	-	-	-	-
OUT-37	03/25/97	7.4	6,600	40	-	8	10.5	39.8	77.2	2,159.1	124	3,434	1.18	-	.08	-
OUT-38	03/31/97	-	-	-	-	-	-	-	-	-	134	2,036	-	-	-	-
OUT-39	04/05/97	-	-	-	-	-	-	-	-	-	60	2,406	-	-	-	-
OUT-40	04/05/97	-	-	-	-	-	-	-	-	-	615	3,622	-	-	-	-

Appendix 3. Selected constituent concentrations at inlet, outlet, and bypass in runoff at stormwater runoff monitoring site, Madison, Wis., 1996–97—Continued

Sample	Date	ph	Conductance (μmho/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Biological oxygen demand (mg/L)		Chemical oxygen demand (mg/L)		Chloride (mg/L)	Total suspended solids (mg/L)	Dissolved solids (mg/L)	Ammonia (mg/L)	NO_2 + NO_3 (mg/L)	Phosphorus (mg/L)	
						Dissolved	Total	Dissolved	Total						Dissolved	Total
OUT-41	04/13/97	7.29	11,500	36	136	9.5	9.5	58.7	90.7	6,639.6	78	9,268	.61	-	.05	-
OUT-42	04/15/97	-	-	-	-	-	-	-	-	-	59	2,826	-	-	-	-
OUT-43	04/15/97	-	-	-	-	-	-	-	-	-	45	1,978	-	-	-	-
OUT-44	04/25/97	-	-	-	-	-	-	-	-	-	65	1,430	-	-	-	-
OUT-45	05/01/97	7.25	2,500	36	83	13	14.5	36.4	85	784.3	170	1,282	<.2	-	.12	-
By-pass																
BYP-1	08/06/96	-	-	-	-	-	-	-	-	-	197	190	-	-	-	-
BYP-2	08/07/96	-	-	-	-	-	-	-	-	-	228	174	-	-	-	-
BYP-4	08/20/96	-	-	-	-	-	-	-	-	-	435	166	-	-	-	-
BYP-5	08/22/96	-	-	-	-	-	-	-	-	-	392	166	-	-	-	.66
BYP-10	10/17/96	-	-	-	-	-	-	-	-	-	537	294	-	-	-	.4
BYP-12	10/23/96	-	-	-	-	-	-	-	-	-	469	404	-	-	-	.4
BYP-13	10/30/96	-	-	-	-	-	-	-	-	-	129	416	-	-	-	-
BYP-18	12/15/96	-	-	-	-	-	-	-	-	-	1,489	1,800	-	-	-	-
BYP-21	01/05/97	-	-	-	-	-	-	-	-	-	2,097	7,536	-	-	.04	.83
BYP-40	04/05/97	-	-	-	-	-	-	-	-	-	1,859	408	-	-		1.65
BYP-45	05/01/97	-	-	-	-	-	-	-	-	-	258	600	-	-	.21	.19

Appendix 4. Polycyclic aromatic hydrocarbon concentrations in runoff samples at the inlet to and outlet from the stormwater-unit treatment chamber

[C, carbon; TOC, total organic carbon; DOC, dissolved organic carbon; PAH, Polycyclic aromatic hydrocarbon; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data]

Sample	TOC (mg/L as C)	DOC (mg/L as C)	Acenaphthene (µg/L)		Anthracene (µg/L)	Benzo(*b*)-fluoranthene (µg/L)	Benzo(*k*) fluoranthene (µg/L)	Benzo(*a*)-pyrene (µg/L)	Chrysene (µg/L)	Fluoranthene (µg/L)	Fluorene (µg/L)		Indeno-(1,2,3-*cd*) pyrene (µg/L)	Napthalene (µg/L)		Phenanthrene (µg/L)		Pyrene (µg/L)	Benzo (*ghi*) perylene (µg/L)	Benzo(*a*) anthracene (1,2)-benzanthracene (µg/L)	1,2,5,6-Dibenzanthracene (µg/L)	PAH (µg/L)
			Total	Dissolved	Total	Total	Total	Total	Total	Total	Total	Dissolved	Total	Total	Dissolved	Total	Dissolved	Total	Total	Total	Total	Total
Inlet																						
IN-1	15	13	<0.048	<.048	0.034	0.79	0.38	0.56	1	1.9	<0.12	<0.1200	0.48	<0.054	<0.054	0.69	0.074	1.2	0.5	0.35	<0.057	7.884
IN-4	15	13	.15	.061	<.075	1.7	.78	1.6	2.1	4.8	.34	.16	1.1	.054	<.054	2.8	.43	3.9	1.2	<.87	.12	20.644
IN-7	62	50	<.048	<.048	<.015	.22	.098	.18	.27	<.510	.15	<.12	.18	<.054	<.054	0.47	.21	<.51	.19	<.059	.021	1.779
IN-8	30	24	<.048	<.048	<.015	.13	<.060	.11	.15	.32	<.12	<.12	.12	<.054	<.054	0.19	.096	.28	.11	<.059	<.019	1.410
IN-9	12	9.9	<.048	<.048	<.015	.25	.11	.22	.26	.51	<.12	<.12	.19	<.054	<.054	0.19	.092	.42	.21	<.12	.025	2.385
IN-10	24	20	<.048	<.048	<.078	1.7	.74	1.1	2	5.1	.3	<.12	.97	.059	<.054	2.2	.13	3.8	1	<.52	.099	19.068
IN-12	14	10	<.048	<.040	.025	.49	.21	.35	.62	1.3	<.12	<.12	.3	<.054	<.054	0.6	.12	1.1	.34	<.18	.35	5.685
IN-13	9.9	8.9	<.048	<.048	<.048	.72	.33	.41	1.1	2.4	.15	<.12	.38	<.054	<.054	0.96	.13	1.9	.39	<.22	.039	8.779
IN-15	37	35	<.048	<.048	--	.78	.33	.62	.91	2.4	<.12	<.12	.54	<.054	<.054	1.5	.17	1.7	.63	<.4	.054	9.464
IN-18	13	8.1	.2	<.048	<.18	1.3	.56	1	<1.7	<3.9	.89	.26	.9	.14	.19	4.9	.56	<5.3	.92	<.69	.093	10.903
IN-21	5.8	5.7	.33	<.048	--	2.7	1.2	2.3	2.8	8.2	1.1	0.2	1.8	.18	.24	7.8	.6	7.1	2.1	<2.1	.2	37.81
IN-23	15	13	9.6	<2.7	<3.7	<.350	<.750	<.65	<8.3	<100	24	4.7	.71	8.6	7	66	5.6	<57	.69	<14	<.054	109.6
IN-37	13	11	<.048	<.048	0.58	.69	.3	.52	.65	1.9	.2	<.12	.47	.074	.12	1.1	.42	1.5	.52	<.48	<.053	8.504
IN-41	8	6.7	<.048	<.048	<.038	.5	.21	.37	.47	1.4	.17	<.12	.3	.081	.099	1	.39	.95	.37	<.38	<.036	5.821
IN-45	18	17	<.048	<.048	.13	1.2	.6	1	1.3	3.8	.16	<.12	.81	<.054	.085	2	.26	2.7	.88	.73	.083	15.393
Outlet																						
OUT-1	20	17	<.0480	<.0480	<.015	.43	.2	.26	.58	1	<.12	<.12	.27	<.054	<.054	.28	.094	.68	.25	.15	<.027	4.100
OUT-4	21	19	.064	--	<.022	.44	.19	.35	.56	1.2	.14	--	.28	<.054	--	.65	--	1	.3	<.27	.029	5.203
OUT-7	78	67	<.048	<.048	.061	.51	.24	.45	.59	1.2	<.12	<.12	.38	.056	<.054	.86	.15	.99	.41	<.26	.041	5.788
OUT-8	31	27	<.048	<.048	<.015	.11	<.059	.095	.12	.3	<.12	<.12	.094	<.054	<.054	.13	.098	.2	.1	<.059	<.019	1.149
OUT-9	11	9.5	<.048	<.048	<.015	.21	.1	.19	.22	.43	<.12	<.12	.17	<.054	<.054	.14	.09	.36	.18	<.12	.02	2.02
OUT-10	29	26	<.048	<.048	<.180	.55	.24	.37	.62	1.3	<.12	<.12	.34	<.054	<.054	.62	.14	.97	.36	<.17	.036	5.406
OUT-12	11	8.6	<.048	<.048	<.015	.32	.14	.2	.4	.76	<.12	<.12	.19	<.054	<.054	.31	.12	.58	.22	<.082	.025	3.145
OUT-13	9.1	8.4	<.048	<.048	.02	.5	.23	.29	.69	1.3	<.12	<.12	.26	<.054	.062	.44	.14	.95	.28	<.19	.03	4.99
OUT-15	40	35	<.048	<.048	<.026	.51	.22	.38	.55	1.2	<.12	<.12	.35	<.054	<.054	.83	.17	.94	.41	<.22	.033	5.423
OUT-18	11	8.7	<.19	<.048	<.130	<1.1	.48	.84	<1.3	<3.1	.75	.22	.8	.18	.14	3.3	.54	<3.6	.89	<.55	.08	7.32
OUT-21	5	5	.25	<.048	--	2.1	.92	1.7	2.2	6	.86	.19	1.4	.13	.25	6.3	.52	5.4	1.7	--	.16	29.12
OUT-23	17	14	6.6	<2.6	<1.9	<.400	<.5	<.041	<5.7	<70	16	4.1	.79	7.7	8.3	45	4.8	<39	.72	<8.2	<.073	76.81
OUT-37	13	10	<.048	<.048	<.015	.53	.2	.3	.48	1.3	<.12	<.12	.32	<.054	.1	.36	.41	.9	.34	<.3	.03	4.76
OUT-41	9.4	8	<.048	<.048	<.021	.4	.17	.24	.36	1.1	.21	.17	.25	<.054	.11	.56	.39	.67	.27	<.28	.024	4.254
OUT-45	13	12	<.048	<.048	<.045	.59	.25	.37	.63	1.9	.15	<.12	.35	<.054	<.054	.69	.27	1.3	.37	<.36	<.039	6.600

Appendix 5. Estimated concentrations of selected constituents for unmonitored runoff periods

[TSS, total suspended solids; DS, dissolved solids; TP, total phosphorus; mg/L, milligrams per liter]

Start date	End date	Inlet (mg/L)			Outlet (mg/L)			Bypass (mg/L)		
		TSS	DS	TP	TSS	DS	TP	TSS	DS	TP
10/6/96 21:17	10/6/96 23:36	182	1,575	0.87	100	1,506	0.65	414	166	0.66
11/4/96 8:22	11/4/96 8:45	472	26,181	.69	219	20,702	.59	-	-	-
11/21/96 9:00	11/21/96 12:00	515	21,669	.53	184	20,204	.32	-	-	-
11/23/96 12:00	11/23/96 13:29	515	21,669	.53	184	20,204	.32	-	-	-
11/26/96 21:00	11/27/96 0:00	515	21,669	.53	184	20,204	.32	-	-	-
11/27/96 8:00	11/27/96 15:00	515	21,669	.53	184	20,204	.32	-	-	-
11/28/96 18:00	11/29/96 2:00	515	21,669	.53	184	20,204	.32	-	-	-
11/29/96 7:43	11/30/96 4:03	339	8,135	.51	264	7,196	.48	-	-	-
12/6/96 11:44	12/6/96 13:18	486	35,598	.48	175	37,810	.28	-	-	-
12/7/96 12:27	12/7/96 13:36	486	35,598	.48	175	37,810	.28	-	-	-
12/13/96 13:06	12/13/96 13:40	486	35.598	.48	175	37,810	.28	-	-	-
3/9/97 5:58	3/9/97 10:18	188	5,108	.19	132	6,570	.16	1,059	504	.92
4/17/97 10:23	4/17/97 10:29	69	1,798	.18	80	2,140	.16	-	-	-
4/18/97 21:41	4/19/97 6:57	213	2,357	.36	188	4,788	.30	-	-	-
4/20/97 15:30	4/20/97 21:00	245	2,357	.32	219	4,788	.28	1,059	504	.92

Appendix 6. Solids and phosphorus loads at the inlet and outlet of the stormwater-unit treatment chamber and removal efficiencies for the treatment chamber

[Inlet and outlet loads in kilograms; efficiencies in percent; boxed value means an estimated concentration was used to compute the load]

Event	Loads (kilograms)						Loads (grams)					
	Total suspended solids			Dissolved solids			Dissolved phosphorus			Total phosphorus		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
1	23	24	-2	35	39	-13	19.8	16.8	15	--	--	--
2	5	2	58	5	5	17	--	--	--	6.1	4.4	27
3	0	0	55	2	1	59	--	--	--	1.6	--	--
4	13	13	5	14	18	-30	9.1	6.6	27	33.0	25.6	23
5	17	11	34	12	13	-14	--	--	--	19.4	16.9	13
6	4	2	54	32	12	64	--	--	--	39.2	24.1	38
7	9	5	44	16	18	-11	21.3	15.9	25	52.6	41.5	21
8	4	3	17	9	12	-37	15.7	5.0	68	26.3	29.1	-11
9	37	37	2	28	30	-8	37.1	21.2	43	106.0	103.3	3
10	38	45	-18	500	320	36	40.8	40.8	0	139.4	101.1	27
11	1	0	84	10	8	22	--	--	--	--	1.9	--
12	27	22	17	167	191	-15	28.4	11.8	58	71.5	73.5	-3
13	51	54	-5	309	312	-1	70.6	64.7	8	--	--	--
14	12	6	48	148	158	-7	--	--	--	21.7	15.5	29
15	9	6	28	710	487	31	12.9	8.0	38	35.4	34.6	2
16	16	6	63	1,110	889	20	--	--	--	9.9	7.9	20
17	1	0	50	86	86	0	--	--	--	--	0.3	--
18	67	48	29	684	742	-8	8.6	6.9	20	70.7	58.6	17
19	49	24	50	1,163	1,993	-71	--	--	--	31.2	25.6	18
20	14	10	30	637	637	0	--	--	--	--	--	--
21	134	144	-7	2,822	3,129	-11	13.6	10.8	21	109.7	108.3	1
22	7	3	56	1,199	1,993	-66	--	--	--	6.0	3.4	43
23	19	24	-27	2,560	3,289	-28	5.7	5.7	0	30.1	22.9	24
24	12	4	68	1,335	1,114	17	--	--	--	6.7	2.6	61
25	30	6	79	1,834	2,323	-27	--	--	--	13.6	2.2	84
26	65	26	60	2,110	2,797	-33	--	--	--	43.6	13.8	68
27	1	1	41	99	144	-46	--	--	--	0.7	0.6	25
28	29	17	40	1,193	1,177	1	--	--	--	12.5	7.0	44

Appendix 6. Solids and phosphorus loads at the inlet and outlet of the stormwater-unit treatment chamber and removal efficiencies for the treatment chamber—Continued

Event	Loads (kilograms)						Loads (grams)					
	Total suspended solids			Dissolved solids			Dissolved phosphorus			Total phosphorus		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
29	2	1	60	45	99	-118	--	--	--	1.5	0.7	52
30	5	1	78	57	269	-371	--	--	--	2.7	0.8	72
31	10	3	71	177	840	-375	--	--	--	5.9	2.6	56
32	20	13	35	340	400	-18	--	--	--	17.4	7.3	58
33	43	35	20	1,574	1,666	-6	--	--	--	37.1	33.8	9
34	224	100	55	4,731	4,854	-3	--	--	--	135.3	83.2	38
35	29	22	24	990	861	13	--	--	--	12.5	13.4	-8
36	20	21	-5	529	760	-44	--	--	--	25.9	27.5	-6
37	28	21	25	199	571	-187	13.3	13.3	0	39.9	33.2	17
38	5	5	-12	67	80	-18	--	--	--	9.4	9.4	0
39	0	1	-40	9	21	-132	--	--	--	2.0	1.3	35
40	43	49	-14	37	287	-679	--	--	--	54.0	56.2	-4
41	22	18	17	1,495	2,171	-45	14.1	11.7	17	39.8	35.1	12
42	8	8	-2	192	390	-103	--	--	--	15.2	8.3	45
43	0	0	0	23	17	25	--	--	--	0.7	0.7	0
44	3	2	26	48	46	4	--	--	--	16.4	12.3	25
45	101	100	1	400	755	-89	83.3	70.7	15	132.1	111.9	15
sum	1,258	943	25	29,743	36,022	-21	394	310	21	1,435	1,162	19

Appendix 7. Treatment chamber dissolved metal loads and reduction efficiencies

[--, not determined; boxed value, concentration between limit of detection and limit of quantitation used to compute the load; shaded values indicate a less than detect concentration was assumed to be zero]

Event	Loads (grams)											
	Dissolved cadmium			Dissolved copper			Dissolved lead			Dissolved zinc		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
1	--	--	--	0.81	0.94	-17	--	--	--	2.59	3.81	-47
4	--	--	--	.35	.53	-52	--	--	--	1.65	3.05	-85
7	0.04	0.01	58	1.23	.60	52	.15	.18	-14	6.59	4.78	27
8	--	--	--	.53	.49	7	--	--	--	2.40	3.64	-51
9	--	--	--	1.03	1.06	-3	--	--	--	15.10	6.09	60
10	--	--	--	1.30	2.33	-79	--	--	--	9.52	8.16	14
12	--	--	--	.85	1.02	-19	--	--	--	11.85	9.48	20
13	--	--	--	1.35	1.82	-35	--	--	--	14.12	21.19	-50
15	.09	.08	3	.25	0	100	.38	.48	-28	--	--	--
18	.27	.18	34	--	--	--	--	--	--	1.16	2.59	-124
21	.17	.40	-135	--	--	--	--	--	--	--	--	--
23	.49	.44	10	1.15	1.15	0	1.57	1.25	21	18.04	17.47	3
45	.12	.11	14	--	--	--	--	--	--	13.55	11.78	13
sum	1.2	1.2	-4	8.8	9.9	-12	2.1	1.9	10	96.6	92.0	5

Appendix 8. Treatment chamber biological oxygen demand and chemical oxygen demand loads and reduction efficiencies

[--, not determined]

Event	Loads (grams)											
	Dissolved biological oxygen demand			Total biological oxygen demand			Dissolved chemical oxygen demand			Total chemical oxygen demand		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
1	--	--	--	1,676	2,133	-27	5,729	7,131	-24	7,390	7,588	-3
4	--	--	--	825	908	-10	2,757	4,218	-53	8,056	5,918	27
7	--	--	--	--	--	--	5,118	4,162	19	8,770	5,225	40
8	--	--	--	1,119	895	20	3,775	4,010	-6	11,241	5,369	52
9	2,649	1,855	30	3,179	2,649	17	--	--	--	--	--	--
10	3,790	4,275	-13	--	--	--	--	--	--	--	--	--
12	1,896	2,204	-16	2,844	3,555	-25	--	--	--	--	--	--
13	4,414	5,296	-20	5,885	5,591	5	--	--	--	--	--	--
15	--	--	--	--	--	--	9,121	8,076	11	9,483	11,894	-25
18	1,293	1,552	-20	2,345	2,242	4	6,294	6,812	-8	29,368	24,039	18
21	1,962	1,759	10	3,248	2,707	17	16,510	20,705	-25	59,679	21,815	63
23	2,026	2,219	-10	4,152	3,866	7	12,943	24,954	-93	27,889	36,279	-30
37	1,662	1,329	20	1,246	1,745	-40	5,832	6,613	-13	12,163	12,828	-5
41	1,523	2,226	-46	1,757	2,226	-27	8,388	13,753	-64	16,190	21,250	-31
45	10,601	7,656	28	15,902	8,540	46	30,449	21,438	30	66,965	50,062	25
sum	31,820	30,370	5	44,180	37,060	16	106,920	121,870	-14	257,190	202,270	21

Appendix 9. Treatment chamber chloride, alkalinity, hardness, ammonia, and nitrate plus nitrite loads and reduction efficiencies

[--, not determined; shaded values indicate a less than detect concentration was assumed to be zero]

Event	Loads (kilograms)									Loads (grams)					
	Chloride			Alkalinity			Hardness			Ammonia			$NO_2 + NO_3$		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
1	15	16	-8	6	6	-5	7	9	-33	70	75	-7	85	105	-23
4	6	7	-25	4	4	4	4	7	-60	36	19	48	23	31	-36
7	--	--	--	--	--	--	--	--	--	63	58	8	--	--	--
8	2	3	-14	--	--	--	--	--	--	26	0	100	34	17	51
9	5	5	-13	--	--	--	--	--	--	64	0	100	127	101	21
10	166	180	-8	--	--	--	12	12	0	80	124	-56	--	--	--
12	95	113	-20	6	6	-8	8	10	-38	123	76	38	--	--	--
13	170	182	-7	12	12	-0	--	--	--	230	247	-8	--	--	--
15	453	296	35	2	3	-79	6	7	-20	46	32	31	--	--	--
18	399	457	-14	26	13	50	19	17	9	83	100	-21	--	--	--
21	1,764	1,985	-13	58	50	15	43	43	-0	271	276	-2	--	--	--
23	1,580	2,064	-31	8	10	-28	36	42	-15	26	0	100	--	--	--
37	120	359	-200	7	7	5	--	--	--	189	196	-4	--	--	--
41	1,071	1,556	-45	10	8	18	250	32	87	145	143	2	--	--	--
45	220	462	-110	21	21	-0	322	49	85	200	0	100	--	--	--
sum	6,066	7,684	-27	160	140	13	706	228	68	1,652	1,346	19	269	254	6

Appendix 10. Treatment chamber total and dissolved organic carbon and total polycyclic aromatic hydrocarbon loads and reductions efficiencies

Event	Loads (kilograms)						Loads (grams)		
	Total organic carbon			Dissolved organic carbon			Total polycyclic aromatic hydrocarbons		
	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency	Inlet	Outlet	Efficiency
1	2.29	3.05	-33	1.98	2.59	-31	1.20	0.62	48
4	1.24	1.73	-40	1.07	1.57	-46	1.70	.43	75
7	3.30	4.15	-26	2.66	3.56	-34	.09	.31	-225
8	1.68	1.73	-3	1.34	1.51	-13	.08	.06	19
9	3.18	2.91	8	2.62	2.52	4	.66	.54	15
10	4.66	5.64	-21	3.89	5.05	-30	3.71	1.05	72
12	3.32	2.61	21	2.37	2.04	14	1.35	.75	45
13	5.83	5.36	8	5.24	4.94	6	5.17	2.94	43
15	1.49	1.61	-8	1.41	1.41	0	.38	.22	43
18	2.24	1.90	15	1.40	1.50	-7	1.88	1.26	33
21	1.57	1.35	14	1.54	1.35	12	10.23	7.88	23
23	2.15	2.43	-13	1.86	2.00	-8	15.69	11.00	30
37	2.16	2.16	0	1.83	1.66	9	1.41	.79	44
41	1.87	2.20	-18	1.57	1.87	-19	1.36	1.00	27
45	10.60	7.66	28	10.01	7.07	29	9.07	3.89	57
sum	47.6	46.5	2	40.8	40.7	0	54.0	32.7	39

Appendix 11. Upstream and downstream solids and phosphorus loads and reduction efficiencies

[--, not determined; efficiencies in percent; shaded value, concentration between the limit of detection and limit of quantitation used to compute load]

Event	Loads (kilograms)						Loads (grams)					
	Total suspended solids			Dissolved solids			Dissolved phosphorus			Total phosphorus		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
1	26.8	27.2	-1	37.8	42.3	-12	22.1	19.0	14	--	--	--
2	5.7	3.0	47	6.3	5.4	15	--	--	--	7.2	5.5	23
3	.4	.2	55	2.1	.9	59	--	--	--	1.6	--	--
4	41.0	40.3	2	24.5	28.6	-17	16.1	13.6	15	58.6	51.1	13
5	24.7	18.9	24	14.9	16.5	-11	--	--	--	32.5	29.9	8
6	3.7	1.7	54	32.4	11.5	64	--	--	--	39.2	24.1	38
7	8.8	4.9	44	16.4	18.2	-11	21.3	16.0	25	52.6	41.5	21
8	3.6	3.0	17	8.5	11.6	-37	15.7	5.0	68	26.3	29.1	-11
9	37.4	36.6	2	27.6	29.7	-8	37.1	21.2	43	106.0	103.3	3
10	140.6	147.4	-5	556.0	376.0	32	80.9	80.9	0	215.8	177.4	18
11	1.2	0.2	84	10.0	7.8	22	--	--	--	--	1.9	--
12	37.0	32.4	13	175.6	200.4	-14	31.1	14.5	53	80.3	82.3	-2
13	77.2	79.9	-3	391.6	394.9	-1	94.6	88.7	6	--	--	--
14	11.6	6.0	48	147.5	157.6	-7	--	--	--	21.7	15.5	29
15	8.7	6.2	28	710.3	486.7	31	12.9	8.0	38	35.4	34.6	2
16	16.3	6.1	63	1,110.4	888.7	20	--	--	--	9.9	7.9	20
17	.6	.3	50	86.0	86.0	0	--	--	--	--	.4	--
18	81.0	61.6	24	700.8	758.3	-8	9.1	7.4	19	74.5	62.4	16
19	48.8	24.4	50	1,163.4	1,992.8	-71	--	--	--	31.2	25.6	18
20	14.2	9.9	30	637.3	637.3	0	--	--	--	--	--	--
21	154.5	164.0	-6	2,894.5	3,202.0	-11	14.0	11.2	20	117.7	116.3	1
22	6.8	3.0	56	1,199.1	1,993.3	-66	--	--	--	6.0	3.4	43
23	19.3	24.5	-27	2,560.2	3,288.9	-28	5.7	5.7	0	30.1	22.9	24
24	12.2	3.9	68	1,334.8	1,114.4	17	--	--	--	6.7	2.6	61
25	30.1	6.4	79	1,834.3	2,322.6	-27	--	--	--	13.6	2.2	84
26	65.5	26.1	60	2,110.2	2,797.1	-33	--	--	--	43.6	13.8	68
27	0.9	0.5	41	98.7	144.1	-46	--	--	--	.8	.6	25
28	29.2	17.4	40	1,193.3	1,176.8	1	--	--	--	12.5	7.1	44
29	2.5	1.0	60	45.3	98.7	-118	--	--	--	1.5	.7	52
30	4.8	1.1	78	57.1	269.1	-371	--	--	--	2.7	.8	72
31	9.6	2.8	71	176.8	839.6	-375	--	--	--	6.0	2.6	56

Appendix 11. Upstream and downstream solids and phosphorus loads and reduction efficiencies—Continued

Event	Loads (kilograms)						Loads (grams)					
	Total suspended solids			Dissolved solids			Dissolved phosphorus			Total phosphorus		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
32	19.6	12.8	35	340.0	400.1	-18	--	--	--	17.4	7.3	58
33	43.1	34.6	20	1,573.7	1,665.7	-6	--	--	--	37.2	33.8	9
34	224.2	100.4	55	4,730.5	4,853.8	-3	--	--	--	135.3	83.2	38
35	28.9	22.0	24	990.1	861.2	13	--	--	--	12.5	13.4	-8
36	20.2	21.2	-5	529.4	760.1	-44	--	--	--	25.9	27.5	-6
37	27.6	20.6	25	198.6	570.6	-187	13.3	13.3	0	39.9	33.2	17
38	4.7	5.2	-12	67.5	79.7	-18	--	--	--	9.4	9.4	0
39	.4	.5	-40	9.2	21.4	-132	--	--	--	2.1	1.3	35
40	57.4	63.3	-10	40.0	289.8	-624	--	--	--	67.0	69.2	-3
41	22.0	18.3	17	1,494.8	2,171.4	-45	14.1	11.7	17	39.8	35.1	12
42	8.0	8.1	-2	192.2	390.1	-103	--	--	--	15.2	8.3	45
43	0.4	0.4	0	23.1	17.4	25	--	--	--	.7	.7	0
44	2.8	2.1	26	48.2	46.1	4	--	--	--	16.5	12.3	25
45	119.6	118.7	1	442.9	798.3	-80	99.2	85.8	13	145.4	125.6	14
sum	1,504	1,189	21	30,043	36,323	-21	487	402	17	1,598	1,326	17

Appendix 12. Upstream and downstream total metals loads and reduction efficiencies

[--, not determined; boxed value, concentration between the limit of detection and limit of quantitation used to compute loads; shaded value, less-than-detect concentration was assumed to be zero, efficiencies in percent]

Event	Loads (grams)											
	Total cadmium			Total copper			Total lead			Total zinc		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
1	0.06	0	100	2.66	2.91	-9	2.66	2.46	7	22.05	22.05	0
4	.14	.08	38	5.83	3.94	32	6.47	4.17	36	35.43	26.35	26
7	.06	.03	50	2.28	1.36	41	1.20	.74	38	16.69	9.73	42
8	--	.02	--	0.82	0.92	-12	.42	.38	9	5.42	5.87	-8
9	.08	0	100	4.50	3.89	14	5.30	4.95	7	34.71	32.06	8
10	.19	0	100	12.37	10.81	13	18.07	13.93	23	144.49	114.56	21
12	--	--	--	3.78	3.05	19	4.25	3.18	25	39.11	31.29	20
13	--	--	--	7.88	8.17	-4	13.55	9.49	30	95.34	87.10	9
15	.20	.16	16	1.33	.84	36	3.38	2.17	36	12.34	9.60	22
18	.49	.32	34	5.99	3.06	49	16.35	10.49	36	58.13	41.23	29
21	1.03	.79	23	15.98	11.92	25	23.55	20.03	15	113.52	100.26	12
23	.47	.56	-21	3.15	4.01	-27	4.87	5.15	-6	36.08	34.50	4
45	.83	.53	36	14.13	5.82	59	24.89	18.41	26	114.36	87.86	23
sum	3.5	2.6	27	80.7	60.7	25	125.0	95.6	24	727.7	602.5	17

Appendix 13. Upstream and downstream dissolved metals loads and reduction efficiencies

[--, not determined; efficiencies listed in percent; boxed value, concentration between the limit of detection and limit of quantitation used to compute loads; shaded value, less-than-detect concentration was assumed to be zero]

Event	Loads (grams)											
	Dissolved cadmium			Dissolved copper			Dissolved lead			Dissolved zinc		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
1	--	--	--	0.90	1.04	-15	--	--	--	2.88	4.10	-42
4	--	--	--	.61	.80	-30	--	0.61	--	2.93	4.33	-48
7	.04	.01	58	1.23	.60	52	.15	.18	-14	6.59	4.78	27
8	--	--	--	.53	.49	7	--	.13	--	2.40	3.64	-51
9	--	--	--	1.03	1.06	-3	--	--	--	15.10	6.09	60
10	--	--	--	2.58	3.61	-40	--	--	--	18.88	17.52	7
12	--	--	--	.93	1.10	-18	--	--	--	12.95	10.58	18
13	--	--	--	1.81	2.28	-26	--	--	--	18.91	25.97	-37
15	.09	.08	3	0.25	0	100	.38	.48	-28	--	.68	--
18	.28	.19	32	--	--	--	--	--	--	1.22	2.65	-118
21	.18	.41	-130	--	--	--	--	1.87	--	--	5.41	--
23	.49	.44	10	1.15	1.15	0	1.57	1.25	21	18.04	17.47	3
45	.14	.12	13	--	--	--	--	--	--	15.47	13.71	11
sum	1.2	1.3	-4	11.0	12.1	-10	2.1	1.9	10	115.4	110.8	4

Appendix 14. Upstream and downstream biological oxygen demand and chemical oxygen demand loads and reduction efficiencies

[--, not determined; efficiencies in percent]

Event	Loads (kilograms)											
	Dissolved biological oxygen demand			Total biological oxygen demand			Dissolved chemical oxygen demand			Total chemical oxygen demand		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
1	--	--	--	1.9	2.3	-25	6.4	7.8	-22	8.2	8.4	-2
4	--	--	--	1.5	1.5	-6	4.9	6.4	-30	14.3	12.2	15
7	--	--	--	--	--	--	5.1	4.2	19	8.8	5.2	40
8	--	--	--	1.1	0.9	20	3.8	4.0	-6	11.2	5.4	52
9	2.6	1.9	30	3.2	2.6	17	--	--	--	--	--	--
10	7.5	8.0	-6	--	--	--	--	--	--	--	--	--
12	2.1	2.4	-15	3.1	3.8	-23	--	--	--	--	--	--
13	5.9	6.8	-15	7.9	7.6	4	--	--	--	--	--	--
15	--	--	--	--	--	--	9.1	8.1	11	9.5	11.9	-25
18	1.4	1.6	-19	2.5	2.4	4	6.6	7.1	-8	30.9	25.6	17
21	2.0	1.8	10	3.4	2.8	16	17.1	21.3	-25	61.8	23.9	61
23	2.0	2.2	-10	4.2	3.9	7	12.9	25.0	-93	27.9	36.3	-30
37	1.7	1.3	20	1.2	1.7	-40	5.8	6.6	-13	12.2	12.8	-5
41	1.5	2.2	-46	1.8	2.2	-27	8.4	13.8	-64	16.2	21.3	-31
45	12.1	9.2	24	18.2	10.8	41	34.8	25.8	26	76.5	59.6	22
sum	39	37	4	50	43	14	115	130	-13	278	223	20

Appendix 15. Upstream and downstream chloride, alkalinity, hardness, ammonia, and nitrate plus nitrite loads and reduction efficiencies

[--, not determined; efficiencies in percent; shaded value, less-than-detect concentration was assumed to be zero]

Event	Loads (kilograms)									Loads (grams)					
	Chloride			Alkalinity			Hardness			Ammonia			$NO_2 + NO_3$		
	Up-stream	Down-stream	Efficiency	Up-stream	Downstream	Efficiency	Up-stream	Downstream	Efficiency	Up-stream	Down-stream	Efficiency	Up-stream	Down-stream	Efficiency
1	16.3	17.5	-7	6.8	7.1	-4	7.6	9.9	-30	78	83	-6	95	115	-21
4	10.3	11.8	-14	6.7	6.6	2	7.3	9.8	-34	64	47	27	41	49	-20
7	--	--	--	--	--	--	--	--	--	63	58	8	--	--	--
8	2.4	2.8	-14	--	--	--	--	--	--	26	0	100	34	17	51
9	4.7	5.4	-13	--	--	--	--	--	--	64	0	100	127	101	21
10	329.8	343.7	-4	--	--	--	23.1	23.1	0	158	203	-28	--	--	--
12	103.3	122.1	-18	6.2	6.7	-8	8.3	11.1	-34	135	87	35	--	--	--
13	227.9	239.6	-5	15.8	15.8	0	--	--	--	307	325	-6	--	--	--
15	452.9	295.6	35	1.5	2.7	-79	6.0	7.2	-20	46	32	31	--	--	--
18	420.2	478.0	-14	27.6	14.5	47	20.0	18.3	9	87	104	-20	--	--	--
21	1,826.8	2,048.4	-12	60.5	51.9	14	44.8	44.8	0	280	286	-2	--	--	--
23	1,580.2	2,063.8	-31	7.6	9.7	-28	36.4	41.8	-15	26	0	100	--	--	--
37	119.7	358.8	-200	7.0	6.6	5	--	--	--	189	196	-4	--	--	--
41	1,071.4	1,555.6	-45	10.3	8.4	18	249.8	31.9	87	145	143	2	--	--	--
45	251.4	493.2	-96	24.2	24.2	0	367.3	94.6	74	229	28	88	--	--	--
sum	6,417	8,036	-25	174	154	11	771	293	62	1,898	1,592	16	297	281	5

Appendix 16. Upstream and downstream total and dissolved organic carbon and total polycyclic aromatic hydrocarbon loads and reduction efficiencies

[efficiencies in percent]

Event	Loads (kilograms)						Loads (grams)		
	Total organic carbon			Dissolved organic carbon			Total polycyclic aromatic hydrocarbons		
	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency	Upstream	Downstream	Efficiency
1	2.5	3.3	-30	2.2	2.8	-28	1.34	0.76	43
4	2.2	2.7	-23	1.9	2.4	-26	3.02	1.75	42
7	3.3	4.1	-26	2.7	3.6	-34	.09	.31	-225
8	1.7	1.7	-3	1.3	1.5	-13	.08	.06	19
9	3.2	2.9	8	2.6	2.5	4	.63	.54	15
10	9.2	10.2	-11	7.7	8.9	-15	7.35	4.69	36
12	3.6	2.9	20	2.6	2.3	13	1.47	.87	41
13	7.8	7.3	6	7.0	6.7	4	6.92	4.69	32
15	1.5	1.6	-8	1.4	1.4	0	.38	.22	43
18	2.4	2.0	15	1.5	1.6	-7	1.98	1.36	31
21	1.6	1.4	13	1.6	1.4	12	10.60	8.25	22
23	2.1	2.4	-13	1.9	2.0	-8	15.69	11.00	30
37	2.2	2.2	0	1.8	1.7	9	1.41	.79	44
41	1.9	2.2	-18	1.6	1.9	-19	1.36	1.00	27
45	12.1	9.2	24	11.4	8.5	26	10.36	5.18	50
sum	57.3	56.2	2	49.2	49.1	0	62.7	41.5	34

Appendix 17. Solids concentrations in water samples that were pumped out of the stormwater-unit treatment chamber

[All concentrations in milligrams per liter; TK-x, means the sample was collected from the treatment chamber at "x" depth during the pumpdown sampling; boxed samples were composited into one sample for analysis]

Sample ID	Date and 24-hour time	Total suspended solids[1] (mg/L)	Dissolved solids (mg/L)
TK-12.47	5/19/97 13:22		
TK-12.00	5/19/97 13:40	51	5,820
TK-11.50	5/19/97 13:58		
TK-11.01	5/19/97 14:33		
TK-10.49	5/19/97 14:49	10	5,031
TK-10.02	5/19/97 15:05		
TK-9.50	5/19/97 15:25	20	16,082
TK-9.00	5/20/97 11:00		
TK-8.57	5/20/97 11:24	19	16,082
TK-8.08	5/20/97 12:30		
TK-6.84	5/20/97 14:16	109	30,576
TK-6.01	5/20/97 14:24	22	14,338
TK-5.48	5/20/97 14:29		
TK-4.86	5/20/97 14:35	87	36,540
TK-4.43	5/20/97 14:39	51	38,958
TK-4.02	5/20/97 14:43		
TK-3.38	5/20/97 14:50	101	67,360
TK-3.12	5/20/97 14:54	100	50,000
TK-2.91	5/20/97 14:58	143	103,126
TK-2.60	5/20/97 15:02		
TK-2.34	5/20/97 15:06	105	70,419
TK-2.08	5/20/97 15:10		
TK-1.83	5/20/97 15:14	503	105,012
TK-1.67	5/20/97 15:20	240	104,092
TK-1.54	5/20/97 15:25	205	92,958
TK-1.40	5/20/97 15:30	150	63,012

[1]Total suspended solids concentrations are probably slightly high due to high dissolved solids concentrations. See page 11 of text (Variability in Concentration of Stormwater Constituents) for further details.

Appendix 18. Runoff volumes and load estimates for the 15 unmonitored runoff events and treatment chamber efficiency and mass retained based upon these estimates

[TSS, total suspended solids; DS, dissolved solids; TP, total phosphorus; kg, kilogram; %, percent]

Start date	End date	Runoff volume (ft^3)			Treatment chamber loads (kg)						Loads bypassing the treatment chamber (kg)		
		Approaching the unit	Through the treatment chamber	Bypassing the treatment chamber	Load in			Load out					
					TSS	DS	TP	TSS	DS	TP	TSS	DS	TP
10/6/96 21:17	10/6/96 23:36	2,312	2,048	264	10.6	91.4	0.050	5.8	87.3	.038	3.1	1.2	0.005
11/4/96 8:22	11/4/96 8:45	110	110	0	1.5	81.6	.002	.7	64.5	.002	--	--	--
11/21/96 9:00	11/21/96 12:00	706	706	0	10.3	433.2	.011	3.7	404	.006	--	--	--
11/23/96 12:00	11/23/96 13:29	328	328	0	4.8	201.3	.005	1.7	188	.003	--	--	--
11/26/96 21:00	11/27/96 0:00	819	819	0	11.9	502.5	.012	4.3	469	.008	--	--	--
11/27/96 8:00	11/27/96 15:00	1,617	1,617	0	23.6	992.2	.024	8.4	925	.015	--	--	--
11/28/96 18:00	11/29/96 2:00	1,510	1,510	0	22.0	926.5	.023	7.9	864	.014	--	--	--
11/29/96 7:43	11/30/96 4:03	6,820	6,820	0	65.5	1,571.0	.098	51.0	1,390	.092	--	--	--
12/6/96 11:44	12/6/96 13:18	317	317	0	4.4	319.5	.004	1.6	339	.003	--	--	--
12/7/96 12:27	12/7/96 13:36	283	283	0	3.9	285.3	.004	1.4	303	.002	--	--	--
12/13/96 13:06	12/13/96 13:40	129	129	0	1.8	130.0	.002	.6	138	.001	--	--	--
3/9/97 5:58	3/9/97 10:18	7,967	7,853	114	41.8	1,135.9	.043	29.3	1,461	.035	3.4	1.6	.003
4/17/97 10:23	4/17/97 10:29	29	29	0	.1	1.5	.000	.1	1.8	.000	--	--	--
4/18/97 21:41	4/19/97 6:57	1,228	1,228	0	7.4	82.0	.013	6.5	166	.010	--	--	--
4/20/97 15:30	4/20/97 21:00	4,877	4,475	402	31.0	298.6	.041	27.8	607	.035	12.0	5.7	.010
	sum	29,052	28,272	780	240.4	7,052	.331	150.7	7,407	.264	18.6	8.6	.018

Treatment chamber efficiency for unmonitored periods

TSS	DS	TP
37%	-5%	20%

Total mass retained in the tank during unmonitored periods (kg)

TSS	DS	TP
89.7	-354	.067

Appendix 19. Fifteen-minute microtoxicity test results for samples collected at the inlet to and outlet from the stormwater-unit treatment chamber

Event	Percent effect[1]	
	Inlet	Outlet
1	20.32	20.32
4	10.36	16.33
7	52.96	93.73
8	31.45	28.23
9	25.19	18.89
10	30.67	30.67
12	15.13	15.5
13	10.85	4.9
15	-93.06	-68.06
18	-15.10	-26.51
21	-47.00	-65.93
23	81.08	77.7
37	37.25	22.75
41	-69.77	-52.09
45	22.52	14.12
mean	7.52	8.70

[1] Percent effect is the decrease in fluorescent light due to mortality in fluorescent bacteria, thus as the toxicity of the sample increases so does the percent effect.

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